FM 5-

WAR DEPARTMENT

ENGINEER FIELD MANUAL

COMMUNICATIONS, CONSTRUCTION, AND UTILITIES

FM 5–10

ENGINEER FIELD MANUAL

COMMUNICATIONS, CONSTRUCTION, AND UTILITIES

Prepared under direction of the
Chief of Engineers

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BY ORDER OF THE SECRETARY OF WAR:

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COMMUNICATIONS, CONSTRUCTION, AND UTILITIES

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CHAPTER 1

ROADS

SECTION I

GENERAL

■ 1. GENERAL.—The planning and construction of military roads require maximum attention and adherence to the fundamentals of simplicity, sound organization, and economy of time, materials, transportation, and force. Maximum use must be made of the existing road net by effecting necessary repairs thereto in order to hold new construction at a minimum. Care is necessary also to insure against the attempted maintenance of too many roads, the result of which may be a complete break-down of the supply system so necessary to the well-being and success of an army. On the other hand, it is essential that an adequate road net be provided and maintained at all times, particularly between supply establishments, for the rate of movement and existence of an army is dependent upon the rate at which it can receive supplies, and this, in turn, depends upon the sufficiency of the road system and the rate at which it can be advanced. The heavy demands of modern warfare, in which emphasis is placed upon mobility and transportation, require that even forward roads be kept fit for the rapid movement of heavily loaded motor vehicles. The great weight of artillery ammunition alone places a tremendous burden on roads, both in open and stabilized warfare. Road traffic is at a maximum during offensive operations when demands for ammunition and engineer materials, in addition to Class I supplies, are at their highest, and when the exploitation of tactical success may depend upon the continuing flow of such supplies to the advancing troops. Scarcely less, however, is the need to maintain communications in a defensive situation, or in one involving retrograde movement.

■ 2. RESPONSIBILITY FOR MILITARY ROADS.—*a. Command responsibility.*—Commanders of divisional and higher tactical units and of sections of the communications zone are responsible, subject to restrictions by higher authority, for the proper utilization of the road net within their areas and for all engineering work thereon. Instructions are issued in the name of the commander and appear ordinarily in the administrative order, if one is issued, or in paragraph 4 of field orders. Details appear in the Engineer Field Order or Annex. It is the duty of the supply section of the general staff to formulate the detailed instructions of the administrative order to carry out the will of the commander. The unit engineer, in his capacity as technical adviser to the unit commander, should submit recommendations, and be prepared to submit detailed plans on the subject of engineer road work and the utilization of the road net. For reasons of strategy, tactics, or logistics, the commander of the theater of operations may place restrictions upon the nature of the traffic on certain roads, prescribe the character of the work thereon, and its priority. In like manner, an army may place restrictions upon its corps, a corps upon its divisions, and the communications zone upon its sections. The division of responsibility for road work between general headquarters, the communications zone, armies, corps, and divisions must be clearly defined in orders and should be changed from time to time to meet the military situation. Higher units may assume responsibility for certain work in the areas of lower units. In an advance, timely preparations should be made for the taking over of road work from forward units by the successive larger units in the rear. The impulse comes from the rear, the communications zone taking over from the armies, the armies from the corps, and the corps from the divisions. This may be on the initiative of the unit engineer of the higher unit, with the approval of the appropriate general staff officer (usually G-4) of his unit.

b. Engineer responsibility.—Under the orders of the unit commander and through the coordination and supervision of the general staff, the unit engineer is responsible for the execution of all road work in his area that has not been assumed by higher units. As technical adviser to the unit commander and his staff, he should at all times possess the necessary information as to the capacity and condition of the road net in his area, the availability of plant, materials, transportation, and additional labor. He should make frequent personal reconnaissance, insure that similar reconnaissances are made by his staff and subordinate commanders, and check all other sources of military information, including air photographs. Military road work in any unit area is normally executed by the engineer troops of the unit, assisted if necessary by attached engineers, civilians, prisoners of war, military prisoners, details or units of other branches, and transportation units. General engineer troops and dump-truck companies are the units commonly employed upon road work.

■ 3. ROAD CAPACITY.—By this term is meant the number of vehicles which can be moved over the road in a given period of time. Capacity is dependent upon the width, structural character, and conditions of the road, and upon the regulation of traffic. Just as a very poor road may have no capacity at all, so the best one may have none with poor traffic control. A good three-track, two-way road is advantageous in that it permits the passage of columns traveling at different rates of speed in the same direction. A four-track highway is, of course, even more desirable. Structural character and condition influence the number of break-downs, which in turn result in traffic blocks. Good road conditions, therefore, assist in the continuous movement of columns without interruption.

Despite a high standard of road construction, the increase in speed of a continuous column will be minimized by the necessary increase in distance between vehicles. From observation it has been found that the maximum capacity is obtained when the speed is about 16 miles per hour, at which speed the distances between vehicles may be reduced to 15 feet. Experience further indicates, however, that increases in speeds up to 25 miles per hour have only a small effect in reducing the maximum capacity. The theoretical capacity of a single lane, under ideal conditions, is about 2,000 vehicles per hour. However, allowing for break-downs and normal delays due to closing up and extending of columns, it is probable that the actual maximum capacity will be only about half of the theoretical. Allowing for the additional delays inherent to vehicles in convoy, it is probable that 750 vehicles per hour is about the working maximum under normal conditions in one-way traffic. If cross-traffic becomes a consideration, as in the case of "turn-out" and "turn-in" traffic on a two-way road, the capacity in each direction may be taken as not to exceed an average of 250 vehicles per hour, with speeds up to 25 miles per hour.

■ 4. Tactical Requirements.—At least one good two-track road or its equivalent is necessary for each infantry division in line. Corps and army troops should be provided additional roads consistent with their needs in any particular situation. The distance at which troops can be supplied by a road varies with the road conditions, the amount of supplies necessary, the type of transportation available, and the tactical situation.

■ 5. Traffic Regulation on Roads.—In order that roads may give the maximum of service it is necessary to regulate the traffic upon them, both as to direction and speed, and to separate slowly moving columns from those which are able to progress more rapidly. Heavy wheeled vehicles, traveling at high velocities, cause considerable damage at curves and near the edges of a road as a result of shear engendered by the driving wheels in traction. Track-laying vehicles cause even greater relative damage and, when moved at excessive speeds, may so impair the road surface as to make major repairs necessary. For these reasons the engineers should be consulted in the preparation of traffic-control regulations and should be called upon for recommendations as to limiting speeds, directions of movement, and classes of vehicles permitted on various roads. In the case of roads under construction, engineers will direct traffic in accordance with the technical considerations involved and in compliance with instructions by higher authority.

■ 6. NOMENCLATURE.—*a. Axial road.*—A road leading toward the front and generally perpendicular thereto. When designated as the principal traffic artery of a division or higher unit, it is called a main supply road. Generally, main supply roads will not be designated in an independent unit in order to allow maximum flexibility in the use of the roads.

b. Belt road.—A road generally parallel to the front; also known as a lateral road.

c. *Course.*—A layer of road material parallel to the subgrade.

(1) *Base course.*—The course which rests upon the subgrade or blanket course and supports the top course.

(2) *Blanket (or insulation) course.*—A layer of aggregate, 1 or more inches in thickness, composed of particles well graded from coarse to fine and generally without bituminous binder. Its function is to prevent the underlying materials of a plastic subgrade from migrating upward into the open spaces of a base course composed of relatively large stones.

(3) *Top course (wearing).*—The course last applied to form the finished surface of the road.

d. Crown.—The difference in elevation between the center of the roadway and its edges; it is usually expressed in inches of crown or in inches of rise per foot.

e. Ditch.—The open side drain of a road, designed to carry water running to it from the roadway and adjacent side slopes.

f. Grade.—A line along the center of the road, which, when viewed horizontally, defines the top-surface profile of a longitudinal section of the finished road. Also, the rate of ascent or descent of a road, expressed in percentage or otherwise.

g. Metal.—Broken stone, gravel, slag, or similar material used in road construction or maintenance.

h. Reserved road.—A road reserved by higher authority for designated traffic.

i. Restricted traffic.—Limitations imposed as to the character of traffic, its speeds, loads, hours of moving, etc.

j. Shoulder.—The portion of a roadway between the edge of the metaled wearing course and the ditch.

k. Subgrade.—The upper surface of the natural foundation upon which the blanket or base course is laid.

■ 7. CLASSIFICATION OF MILITARY ROADS.—*a. Standard roadways.*—All roads designed and constructed in general accordance with civil practice may be considered as belonging to this classification, within which they may be further classified as having:

(1) High-type surfaces, composed of paved surfaces of blocks, cement concrete, bituminous concrete, or macadam.

(2) Low-type surfaces of gravel, shale, shell, coral, sand-clay, or earth.

b. Improvised or hasty roads.—Under this heading may be considered all roads of cruder nature, intended by way of expedients to move traffic across otherwise impassable zones or areas. Such roads are similar in type and purpose to the temporary construction roads built by contractors in civil practice. Included are plank roads, corduroy roads, metal mesh roads, tread roads, and trails. (See pars. 34–38.)

■ 8. MINIMUM DESIGN REQUIREMENTS.—Except for improvised or hasty roads, built to meet the exigencies of a particular situation, all roads should be constructed with a view to their use by heavy motor vehicles and should be designed to facilitate such movements. With this in mind, certain minimum standards are established, though it is realized that failure to achieve these may, in many situations, be the rule rather than the exception. The real criterion is the successful passage of traffic to meet the tactical situation. For roads built in times of peace for possible use in war it is desirable that heavy duty surfacing be provided, but high-type, flexible surfacing will usually be satisfactory. Such surfacing should be at least 20 feet wide and should be capable of supporting 9,000-pound wheel loads on pneumatic tires. This type of road will support any track-laying vehicle in the service. In flat or rolling country, grades should not exceed 5 percent, or curvature, 6°; in mountainous regions these limits may be increased to 8 percent and 14°, respectively. In the case of tactical roads, the surfacing should be as good as conditions permit and should be adequate to support the maximum wheel loads of the unit for which the roads are built or maintained. A minimum width of 9 feet is desirable for a single column of traffic, while 18 feet are required for two columns. Grades should not exceed 10 percent, and sharp curves should be avoided. In general, the radius of curvature should be in excess of 150 feet, and, if this is not possible, additional lanes, 10 feet wide, should be provided. Overhead clearance should be at least 11 feet and 14 feet if possible.

■ 9. MATERIALS.—In order to expedite construction, reconstruction, maintenance, or repair, and to conserve transportation, military road construction utilizes local materials wherever possible. These materials may be earth, gravel, shell, coral, cinders, rock, broken concrete, blocks, bricks, or timber.

■ 10. TRAFFIC SIGNS.—*a. Necessity.*—Traffic signs, now universally used in peace, are much more necessary in war to guide constantly shifting troops and transport in unfamiliar regions. They are used to mark dangerous curves and crossings; geographical locations, such as towns and villages and the important points therein; cross roads and road junctions, indicating where the roads lead therefrom; the location of and direction to important military centers, such as unit headquarters, depots, parks, dumps, refilling and relay points, airdromes, hospitals, ambulance stations, collecting stations, aid stations, artillery positions, assembly positions, distributing points, railheads, regulating stations, and other establishments. Road and traffic signs are placed by or under the supervision of the engineers, in accordance with the road circulation plan.

b. Character.—Traffic signs should be simple and so arranged as to be unmistakable in their meaning. Their size should be commensurate with the purpose for which they are intended. Lettering on signs along a trail used only by foot troops should be from 1½ to 5 inches high whereas, on principal roads, the signs should be provided with letters from 12 to 15 inches high. The letters and their background should be in sharp contrast, such as black against white or chrome yellow. Luminous paint should be used if available. Especially important signs should be illuminated by lanterns or electric lights at night if the situation permits. To catch the eye quickly and aid illiterates, distinguishing marks should be used, such as division or branch insignia where applicable. Directional arrows should be directive and clear.

■ 11. EFFECTS OF TERRAIN AND CLIMATE ON ROADS AND ROAD WORK.—*a. General.*—One of the principal factors controling a choice of road type is that of climate. In dry, desert countries different problems are presented than in arctic wastes or swampy, backwater country; a road well suited to the one condition may, therefore, fail utterly in the other. The most practical way of determining the kind of road best adapted to local conditions is to observe the roads already built and in use. The advice of local construction men and engineers should be sought as to type of road to construct. If no roads are in existence to serve as guides, principal consideration should be given to moisture content and the means of increasing or diminishing it.

b. Roads in arid regions.—These form an exception to the general run of roads, in that moisture is lacking as a binder. It must therefore be supplied, or some means of surfacing must be found which will not disintegrate as it dries. Certain chemicals, such as calcium chloride, serve to collect moisture from the air, and their use is further discussed under the subject of stabilized roads in paragraph 32. The same chemicals also serve to reduce or prevent dust, which, when it rises in clouds, may betray the movement of a column. Salt water or sea water, if available locally, may be hauled in tank trucks to advantage, as a substitute for fresh water.

c. Roads in cold climates.—In arctic regions, where the road surface is permanently frozen, the main consideration may be that of preventing slipping. This may be accomplished by covering the surface with ashes, cinders, sand, pea gravel, or similar materials. When freezing and thawing occur alternately, attention must be given to drainage of the subgrade in order to prevent heaving. Snow and ice may be removed by hand shoveling or by the use of the special machinery described in paragraph 44.

d. Roads in tropics.—Because of the abundance of rain during certain seasons of the year, drainage is an important consideration. In general there will be a lack of material for concrete or gravel roads, but use can be made of lava rock or coral to construct very suitable roads. The latter is quite soft, hence roads built with it are subject to considerable wear and must be carefully maintained.

■ 12. IMPROVED AND UNIMPROVED ROADS.—Although these words have no clear-cut technical significance, they are often used in a tactical sense to differentiate between all-weather, hard-surfaced roads, suitable for motor traffic, and low-grade roads adaptable only to the movement of animal-drawn vehicles and foot troops, except in the best of weather. In general an improved road may be considered as a high-type road with two or more traffic lanes, while an unimproved one may be counted upon to require considerable improvement and maintenance and to afford only one lane for the movement of traffic.

SECTION II

RECONNAISSANCE

■ 13. GENERAL.—Continuing reconnaissance is no less vital to the success of engineering missions than to those of a purely tactical nature and in no phase of military engineering is there greater need for anticipatory planning than in the establishment and maintenance of highway communications. Such great quantities of materials are needed for the construction, maintenance, and repair of roads that unless they can be obtained from nearby sources they may be unobtainable. Furthermore, intelligent planning of work requires definite information as to the actual condition of roads which are being used or may be used in the future. This can be determined only as the result of field reconnaissance. The resulting report depends upon the uses to which it is to be put, and may vary from a simple statement on conditions and capacities of roads in the area to a complete cataloging of all information concerning the road net in question.

■ 14. ROAD RECONNAISSANCE.—Road reconnaissance may be one of four kinds:

Tactical.—Reconnaissance for information of roads to be used as a basis for tactical operations.

Technical.—Reconnaissance to obtain technical data to be used as the basis of engineering road operations.

Location.—Reconnaissance for new road construction.

Periodic.—Road inspection.

a. Tactical reconnaissance.—(1) *Information required.*—A road reconnaissance, designed to secure information for formulating tactical plans, should indicate the geographical location of routes, and the general character of roads within the area, including specific data as to widths, existing conditions, and loads which may be safely sustained. In addition, the reconnaissance should bring out in certain situations the location of any critical points at which enemy activity against the roads might vitally affect our operations, and should also determine what roads are visible from the enemy position and hence restricted to night traffic unless camouflaged.

(2) *Report.*—This reconnaissance report is used by the staff in making up tactical plans, plans for the location of supply installations which depend upon roads, and plans for the circulation of traffic during operations. To best serve this purpose, the report should be brief and, if possible, should present the essential facts graphically. A very suitable report may be prepared by marking with different colored pencils on a road map or an overlay of an aerial photograph. Such information might include designation of roads suitable for two-way motor traffic; indication of the availability of loops; statements of damage to roads by enemy activity and weather; and locations and conditions of stream crossings, including possible locations of temporary bridges and fords.

b. Technical reconnaissance.—(1) *Information sought.*—The first reconnaissance to obtain engineering data is similar to that conducted for tactical purposes, but is more extended and detailed in character. As a result of it, plans are made for the disposition of engineer troops and supply arrangements are formulated for the operation. Some of the additional items of information sought by such a reconnaissance are data on grades; the location, condition, and capacity of all bridges and culverts; statements as to kinds of road surfaces; dimensions, including width and thickness of pavements, and curvature; and, lastly, the actual location of needed repairs, together with an estimate of men, materials, and time required to effect them. In this connection, information should be appended as to the locations of all possible local materials, such as rock, timber, lumber, slag, or gravel which might be used for road work.

(2) *Form for report.*—In addition to a map or overlay of the type indicated as a basis for a tactical report, a report in the following general form is suggested:

REPORT OF ROAD RECONNAISSANCE

1. Road reported upon --
(Name or designation of road, and points between which inspection was made.)

----

2. Date of reconnaissance --
3. Character of road --
(Concrete, macadam, gravel, earth, etc.)
4. Thickness of pavement --
(Indicate if estimated.)
5. Usable width --
(Also indicate whether one-, two-, or three-track.)
6. Limiting grades --
7. Bridges and culverts:

Location	Dimensions	Capacity	Conditions

8. Priority and nature of needed repairs or improvements:

Location	Work needed	Estimated man-hours	Materials required

9. Materials available locally:

Kind of material	Location	Quantity
....	....	....
....	....	....
....	....	....

....
(Name, grade, organization.)

c. Location reconnaissance.—(1) *Hasty location.*—In forward areas of the combat zone where careful location surveys are prohibited by lack of time and enemy activities, roads and trails are located largely by eye, after a personal reconnaissance. In rear areas of the combat zone the location is as careful as conditions permit, since careful location economizes material and labor. In either case the road location is shown by making use of maps and/or aerial photographs. If neither of these is available, sketch maps may be made by the usual reconnaissance methods. The location, while primarily such as will satisfy the demands of military operations, aims at keeping the earthwork, cuts, and fills to a minimum and economizing in the haulage of surface materials. The alinement and grade of the road is indicated to the constructing troops by means of stakes on the center line at necessary intervals. The cut or fill is marked on the side of the stake. Such roads will follow the surface of the ground as far as possible.

(2) *Careful location.*—When time is available, the steps in the location of a road are—

(*a*) A reconnaissance with the best available map to determine which of several possible routes should be selected.

(*b*) A detailed and accurate survey of a belt of terrain on the general route selected, sufficiently wide to include all probable locations. This provides the data for final location and construction. The main traverse is run on the most probable location, and level notes are taken at 100-foot sections to a suitable distance on each side of the center line.

(*c*) The final location of the center line of the road as determined from the map and notes of the preliminary location. This is placed on the map and the line staked out on the ground.

(3) *Estimation of earthwork.*—The ground profile along the center line of the selected route having been plotted to an exaggerated vertical scale, a line is then so drawn as to effect a near balancing of cuts and fills without exceeding at any point the maximum gradient. This line represents a horizontal projection of the road's axis. For determining accurately the volume of earthwork in cut and fill, cross sections are taken at intervals along the route and plotted to scale on cross-section paper. Upon each of these sections, and in proper relation thereto, is plotted a cross section of the proposed road, the elevation of which has been taken from the profile. The area of cut or fill at each section is then readily determined by use of a planimeter or by counting squares, after which volumes are computed by either the prismoidal formula or by averaging end areas. Rough estimates are facilitated by the use of table I, which gives the volumes of cuts or fills in cubic yards, per 100 feet of length, for each of which the average depth in center cut or fill has been determined from the profile.

TABLE I.—*Volumes of cuts or fills in cubic yards per 100 feet of length*

	Center cut or fill in feet	Width of base of cut or crown of fill in feet					
		14	16	18	20	22	24
Side slopes: 1 on 1	1	56	63	70	78	85	92
	2	119	133	148	163	178	192
	3	189	211	233	256	278	300
	4	267	296	326	356	385	415
	5	352	389	426	463	500	537
	6	444	489	533	578	622	667
	7	544	596	648	700	752	803
	8	652	711	770	830	889	948
	9	767	833	900	967	1,033	1,100
	10	889	936	1,037	1,111	1,185	1,259
	11	1,019	1,100	1,181	1,263	1,344	1,426
	12	1,156	1,244	1,333	1,422	1,511	1,600
	13	1,300	1,396	1,493	1,589	1,685	1,781
	14	1,452	1,556	1,659	1,763	1,867	1,970

TABLE I.—*Volumes of cuts or fills in cubic yards per 100 feet of length*—Continued

	Center cut or fill in feet	Width of base of cut or crown of fill in feet					
		14	16	18	20	22	24
Side slopes: 1 on 1	15	1,611	1,722	1,833	1,944	2,055	2,166
	16	1,778	1,896	2,015	2,133	2,251	2,370
	17	1,952	2,078	2,204	2,330	2,456	2,581
	18	2,133	2,267	2,400	2,533	2,666	2,800
	19	2,322	2,463	2,604	2,744	2,885	3,025
	20	2,519	2,667	2,815	2,963	3,111	3,259
	21	2,722	2,878	3,033	3,189	3,344	3,500
	22	2,933	3,096	3,259	3,422	3,585	3,748
	23	3,152	3,322	3,493	3,663	3,833	4,003
	24	3,378	3,556	3,733	3,911	4,089	4,266
	25	3,611	3,796	3,981	4,167	4,352	4,537
Side slopes: 2 on 1	1	59	67	74	81	88	96
	2	133	148	163	178	193	207
	3	222	244	267	289	311	333
	4	326	356	385	415	444	474
	5	444	481	519	556	593	630
	6	578	622	667	711	755	800
	7	726	778	830	881	933	985
	8	889	948	1,007	1,067	1,126	1,185
	9	1,067	1,133	1,200	1,267	1,333	1,400
	10	1,259	1,333	1,407	1,481	1,555	1,629
	11	1,467	1,548	1,630	1,711	1,792	1,874
	12	1,689	1,778	1,867	1,956	2,045	2,133
	13	1,926	2,022	2,119	2,215	2,311	2,407
	14	2,178	2,281	2,385	2,489	2,593	2,696
	15	2,444	2,556	2,667	2,778	2,889	3,000
	16	2,726	2,844	2,963	3,081	3,200	3,318
	17	3,022	3,148	3,274	3,400	3,526	3,652
	18	3.333	3,467	3,600	3,733	3,866	4,000
	19	3,659	3,800	3,941	4.081	4,222	4,362
	20	4,000	4,148	4,296	4,444	4,592	4,740
	21	4,356	4,511	4,667	4,882	4,977	5,133
	22	4,730	4,889	5,052	5,215	5,378	5,541
	23	5,111	5,281	5,452	5.622	5,792	5,963
	24	5,511	5,689	5,867	6,044	6,222	6,400
	25	5,926	6,111	6,296	6,481	6,666	6.851

d. Periodic reconnaissance.—Periodic reconnaissances are made in connection with road maintenance. Their purpose is to determine current conditions on all the roads, the density of traffic using the roads, the progress of maintenance work, and the results of various methods of maintenance. The resulting reports are used to keep an up-to-date road situation map which is used as a basis both for tactical and supply operations and for the employment of road maintenance troops. Some of the inspections should be made during wet weather to determine the efficiency of the drainage system.

SECTION III

CONSTRUCTION

■ 15. GENERAL.—The basic consideration of all road construction is to provide adequate drainage under all conditions. This is tersely expressed by military engineers in the slogan, "Get the water off and the rock on." No subgrade will long sustain heavy loads unless it is kept reasonably dry by effective drainage. In addition it must be well prepared and well consolidated before the base course is laid. The base course should be composed of well-graded materials so rolled together that maximum compaction is obtained. The top, or wearing course, must be hard enough to sustain the traffic for which the road is prepared and to resist excessive wear. In planning military roads it should be remembered that sometimes the longer way around will be the shorter in the end. Routes should be selected with a view to minimizing work rather than obtaining perfection. Civil standards are generally much too high for the military engineer, who must use expedients to the maximum. Excavation will consist often of little more than a shallow trench to receive the road metal and necessary ditching. In this same connection it is advisable to get the subgrade and top of each course smooth and hard before putting on the next one. Then if the work has to be stopped at any time there will always be some kind of a roadway available for use. Much time and labor can be saved by taking full advantage of the existing road net and never building a new road when an old one can be repaired. Frequently the mere act of providing adequate drainage will transform an impassable road into a fairly good one.

■ 16. Drainage Systems.—Rainfall can cause serious damage to roads unless it is promptly and efficiently removed. If allowed to stand upon the surface of an unpaved road, it will so saturate that surface as to bring rapid failure under the action of traffic. Such water is removed from the surface by providing a crown or rise at the center; superelevation of one edge has the same effect. The amount of crown should increase with the roughness and flexibility of the road surface. Thus for a concrete road the crown might be $\frac{1}{10}''$ per foot, and for a dirt road, 1'' per foot of width from the edge to the center line. Similarly, if allowed to stand alongside the road, water quickly saturates the foundation, which, if unable to rid itself of the accumulated moisture, may also fail by loss of resistance to shear. Means of removal include longitudinal ditches and gutters, culverts (and bridges), and subdrains. Ditches paralleling the road serve to catch and carry away the water running from adjacent side slopes and from the road surface itself by virtue of its crown; culverts prevent the backing up of water behind embankments; subdrains, consisting of various kinds of pipe and stone-filled trenches, are necessary, in certain situations, to keep the road bed firm and as free from water as possible.

■ 17. Ditches.—Side ditches are made either V-shaped or trapezoidal, and may be either paved or unpaved. In military road construction paving of ditches is seldom attempted, being usually unnecessary except on very steep slopes where the soil is easily eroded. In such cases brush or cobble stones generally suffice to hold the bottom, or brush checks staked in place at intervals may be used. Ditches were formerly made deep enough to carry subsoil water in addition to surface water, but modern practice is to avoid deep ditches as dangerous to traffic. The required capacity is obtained by making them wide and diverting the water into culverts or intercepting ditches at frequent intervals. For usual conditions the slope from the outside of the shoulder to the bottom of the ditch may be 3 horizontal to 1 vertical, and the depth may be from 12 to 24 inches. No ditch should be constructed with a gradient less than 0.5 percent.

■ 18. CULVERTS.—*a. Types.*—On temporary roads these will usually be of the simplest kind. If planking and timbers are available, boxes, square or rectangular in cross section, may be constructed for the purpose. Care should be taken to

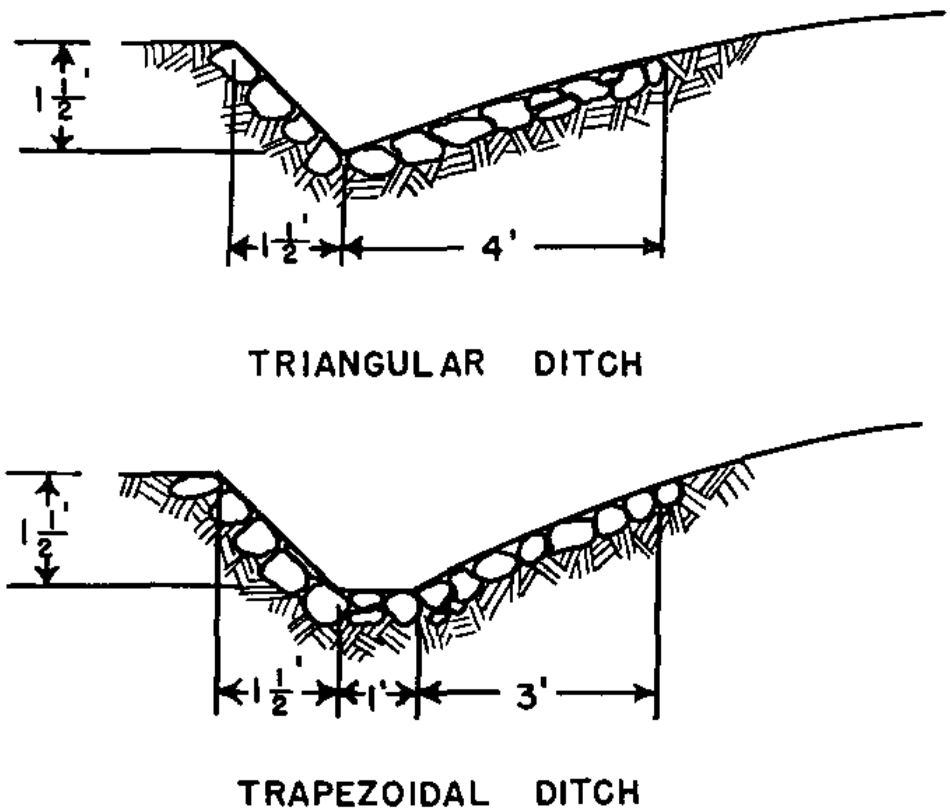


FIGURE 1.—Types of ditches.

make them amply strong to withstand the loads passing over them. Concrete or corrugated metal pipe is excellent for culverts and should be used whenever it is found available. Several such pipes may be laid side by side to obtain increased capacity. All culverts should be covered with at least 18 inches of earth. Wider ditches, up to about 12 feet, may be bridged by laying suitable stringers upon properly seated timber sills and providing the necessary flooring. Stringers should be at least 10 inches in diameter if round and 3 by 12 inches in section if rectangular; poles 4 to 6 inches in diameter or 3- to 12-inch planks may be used as flooring. Round pole decking should be covered with sufficient earth, gravel, or sod to form a fairly smooth roadway.

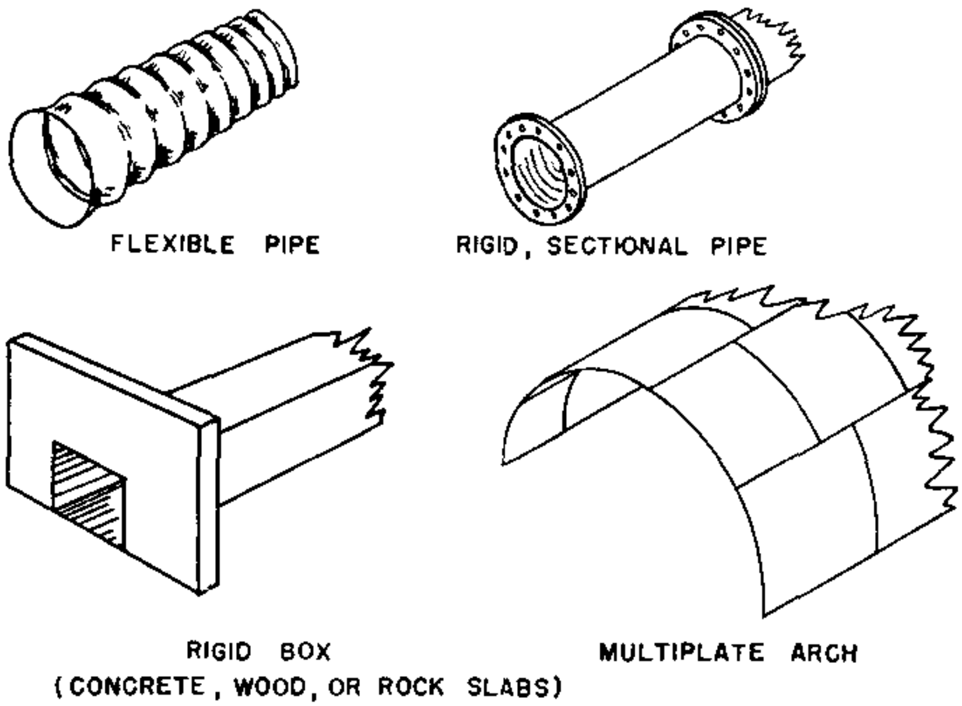


FIGURE 2.—Types of culverts.

b. Protection against scour.—Headwalls of concrete or rubble masonry generally involve more time and labor than can be spared by engineers in a military operation, and a simple substitute is to extend the pipe or box well beyond the edge of the fill at the outlet end. Riprap may be used to protect the foundation bed and the slopes against scour.

c. Design of culverts.—Figure 3, based on Talbot's formula, gives in square feet the cross-sectional areas necessary. In connection with this chart it should be remembered that the cross-sectional area required in a culvert will vary, not only with the size and character of the drainage area, but with the rate of rainfall, the character and condition of the soil, the grade of the culvert, the form of the inlet, and the conditions at the outlet. The best practical guide to design is observance of other culverts in the area and information obtained from local residents. In some localities it will be found that a comparatively small amount of water has worn a ravine of considerable size. This occurs where the soil is light and easily eroded after droughts, as in arid climates. In such cases a brief investigation of the drainage area will

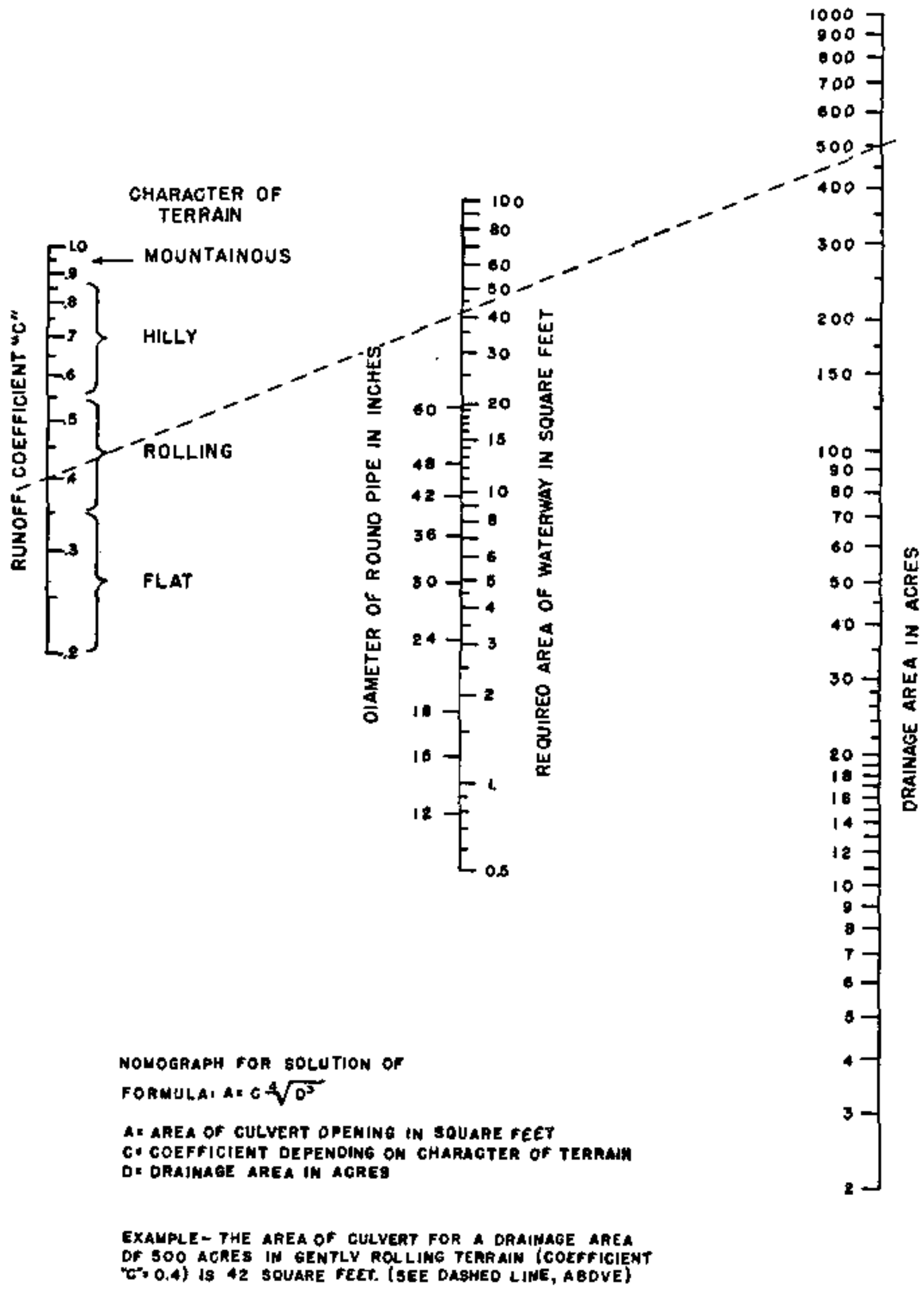


FIGURE 3.—Nomograph based on Talbot's formula

determine the size of the culvert. Culverts should always be made larger than appears necessary, as otherwise they are almost certain to be too small. Similarly, they should be given all the slope possible in order to speed up the cross flow. Another formula for determining the cross-sectional area of culverts is that of Myer, which is widely used for region of this country between Minnesota and the Pacific. With A and D in the same units as in Talbot's formula and C varying from 1.0 for flat or slightly rolling ground to 4.0 for mountainous or rocky terrain, the formula is: $A=C\sqrt{D}$. Myer's formula has the same general limitation as that of Talbot and is less generally applicable.

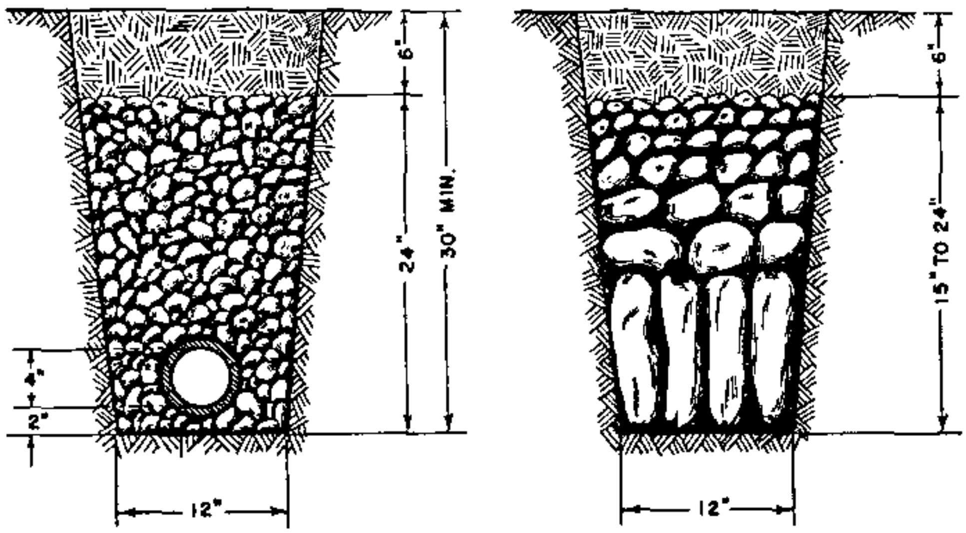


FIGURE 4.—Tile and stone subdrains.

d. Expedients to supplant culverts.—Where materials for culverts or bridges cannot be obtained, small streams or ditches may be crossed by sloping down the banks and paving the bottom with large, nearly flat stones. This method has proved very useful in arid or semiarid regions. Concrete can be used in such cases or large stones may be employed, cement grout or asphalt mixes being used to fill the voids and to make a smooth surface. To minimize the danger of undercutting, paving materials should be laid to produce a wearing surface nearly flush with the stream bed. Since undermining occurs generally on the downstream side, suitable riprap should be employed there as protection. A low sill of logs or boulders 10 or 15 feet downstream from the crossing will assist in holding the foundation in place.

■ 19. SUBDRAINS.—There are two general types of subdrains, tile drains and stone drains. The latter are also known as French or blind drains. Both types are illustrated in figure 4, which gives the generally controlling dimensions. Perforated pipe, if available, may be used in place of the tile indicated in the drawing, in which case the perforations are placed down so as not to clog. When subdrains are required, they are usually located on one or both sides of the road under the longitudinal surface ditches or gutters. In soils that would otherwise retain water beneath the pavement, lateral subdrains may also be provided for leading the water to those at the sides of the road. The laterals should be laid downgrade in herringbone fashion at angles of about 60° to the center line, as shown in figure 5.

Subdrains may be employed on flat roads where water from adjoining areas collects along the road beds, on roads underlaid with retentive subsoils, and on roads having cuts through seeping banks and slopes; it is better practice, however, to raise the entire road profile and deepen side ditches, time permitting. Another common practice is to use a single longitudinal drain of the type shown in figure 4, under the middle of the road, with lateral drains leading into it from the shoulders. The use of subdrains is especially advantageous in soils where there is liability of considerable heaving by frost action, because the longitudinal drain may then function prior to thawing of the soil under the shoulders.

■ 20. NEW CONSTRUCTION.—The following are necessary steps in the construction of any new road after surveys have been completed and the designs prepared.

a. Clearing.—The right-of-way must first be cleared for the necessary width on each side of the center line of all trees, brush, and other vegetable matter. Trees are cut down with axes and saws or explosives and removed in the most expeditious manner, whole or in sections. When stumps are to be grubbed, the trees are usually cut above, but not over three feet from, the ground; if the stumps are to be left, it is customary to cut off the trees at the level of the ground.

b. Grubbing.—The space required for the roadbed and necessary shoulders and side drains must next be cleared by

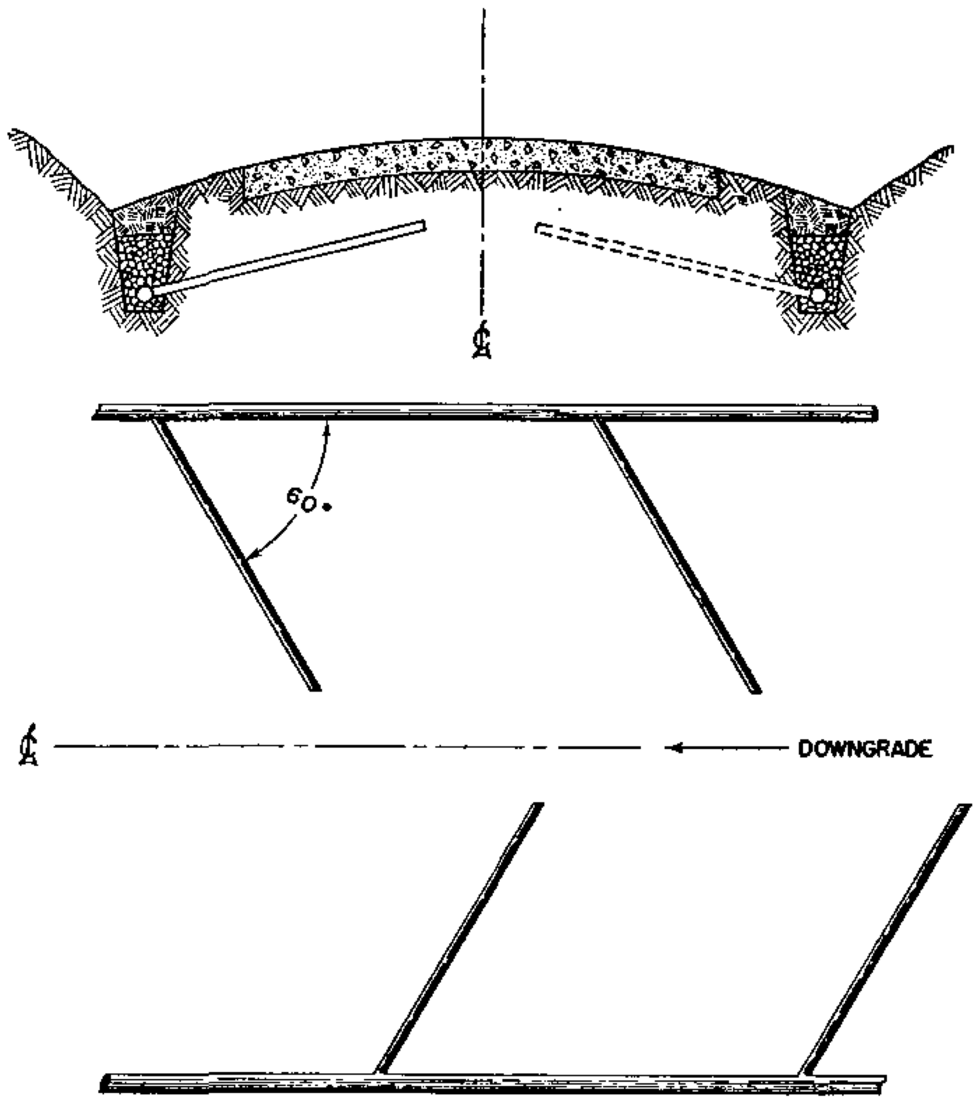


FIGURE 5.—Method of employing lateral drains.

grubbing all stumps and other vegetable matter. In fills over one foot high it is unnecessary to remove stumps that are cut flush with the ground. Stumps may be removed by digging, pulling, burning, blasting, or by a combination of these methods. Burning and digging are processes generally too slow for military work. When the stumps are few and small, pulling is a rapid method. This is accomplished by specially constructed stump pullers, by tractors, or with animals. For the removal of large scattered stumps, explosives furnish the most rapid and economical method both in civil and military practice. For the removal of large stumps in considerable numbers, a combination of blasting and pulling is the most efficient method. Explosives split the stumps, which are pulled by tractors or other pullers noted above.

TABLE II.—*Clearing and grubbing*

Width feet	Man-hours per 100 lineal yards		
	Light clearing	Medium clearing [1]	Heavy clearing
30	10–40	40–105	105–630
40	14–55	55–140	140–840
50	18–70	70–175	175–1050

[1] In the eastern part of the United States the average for this class of work is about 350 man-hours per acre.

c. Grading.—This term comprises all the work preliminary to the finished shaping, and includes practically all earthwork. Cuts and fills are made according to survey or sketch notes and data transferred to the grade stakes. Slope stakes mark the limits of cuts and fills. In the making of fills the earth should be deposited in thin layers, 6 to 8 inches deep, extending from slope to slope, and each layer must be well compacted either with a roller or by driving over it with trucks or wagons in the process of the work. Cuts and fills are made with various types of equipment, varying from pick and hand shovels to power shovels, steam rollers, scrapers, and large dump trucks. Allowances must be made for shrinkage, which will seldom be less than 10 percent. For approximate estimates of shrinkage, 15 percent may be assumed for fills over 2 feet deep and 20 percent for fills less than 2 feet deep. Table III contains data necessary as a basis for calculations relative to earth handling by hand labor.

TABLE III.—*Data on earth handling*

Type of material	Cubic yards per man per hour						
	Excavation with pick and shovel to depth indicated				Loosening earth		Loading in trucks or wagons—man with shovel in loose soil
	0 to 3 feet	0 to 5 feet	0 to 8 feet	0 to 10 feet	Man with pick	Man with 2-horse plow	
Sand	2.1	1.8	1.5	1.5			1.8
Sandy loam	2.0	1.7	1.4	1.3	6.0	60	2.4
Gravel, loose	1.5	1.4	1.2	1.1			1.7
Common loam	1.3	1.2	1.0	1.0	4.0	40	2.0
Light clay	.9	.8	.7	.7	1.9	27	1.7
Dry clay	.6	.6	.5	.5	1.4	20	1.7
Wet clay	.5	.5	.5	.4	1.2	17	1.2
Hardpan	.4	.4	.4	.4	1.4	20	1.7

d. Preparing subgrade.—The subgrade excavation is usually a shallow trench of which the surface (subgrade) is parallel to the finished surface of the road and of the same width. The sides of the trench, which serve to hold the courses in place, are formed by the earth shoulders at least 4 feet in width. In the case of improvised roads, trenching may be omitted. The subgrade should be brought to true line and grade and be thoroughly compacted with rollers or trucks. Any low spots which appear during compaction should be brought up to grade with good material and rerolled. The use of a templet is advisable to obtain the crown. Figure 6 shows elevation of a templet suitable for this purpose.

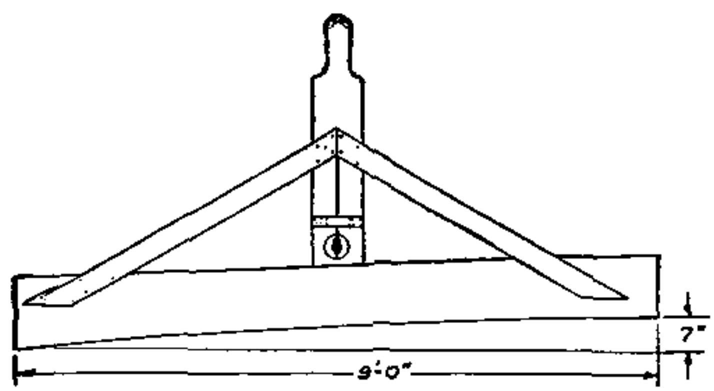


FIGURE 6.—Road templet.

e. Laying the blanket, base, and top courses.—The subgrade being now thoroughly compacted, the next step is to lay the various courses comprising the road itself. In case the subgrade gives evidence of softening excessively with moisture, and it is proposed to use a base course of rather coarse rock, a thin blanket course should be laid to keep the fines of the subgrade from working upwards. If rock forms the subgrade it may be desirable to place a cushion layer of sand to prevent pulverization of metal in the base course. Almost any material such as rock, gravel, slag, shell, coral, or earth may be used in the base course and each will require a somewhat different technique in handling and placing. One principle, however, is applicable to all, and that is: so grade the material particles as to size, that when mixed and rolled they will form a homogeneous mass with a minimum of voids. The wearing course is the last to be applied and, as such, should be designed to provide a hard, smooth surface for traffic, a waterproof covering for the road, and wear-resisting medium for the protection of the base course. It is desirable, when time and materials permit, to place a seal coat on the otherwise finished surface as a final means of excluding percolation.

f. Traffic guards.—Guardrails and similar devices are designed primarily to afford greater safety to traffic, but, if set in closer to the edges of the pavement, may be used to keep vehicles off the soft shoulders of a newly constructed road. Good expedients for use in connection with military roads are pickets, inclined outward, large rocks, or mounds of earth set at intervals on the shoulders outside the edges of the metaled surface.

■ 21. WIDENING OF ROADS.—This should be accomplished by equal widening on both sides when conditions permit. The earth shoulders should be excavated to a depth sufficient for laying the artificial foundation and wearing surface, while preserving the crown so that drainage into the ditches is not obstructed. The widening should be carried out on one side at a time over a section of the road. The bonding of the new portions with the old is very important, and care should be taken to prevent the formation of a ridge which will hold water on the surface. Figure 7 shows one good method of widening a 9-foot road to 18 feet. Curves should be widened on the inside if possible.

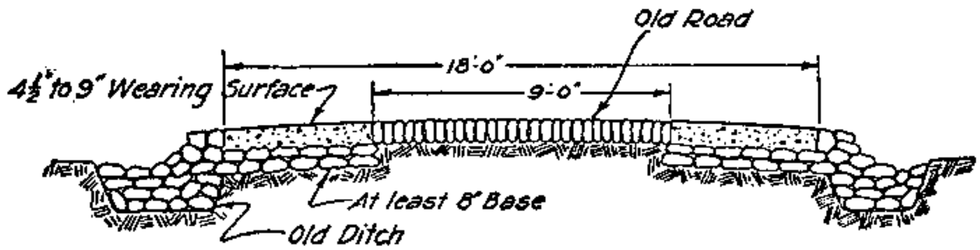


FIGURE 7.—Widening old road.

SECTION IV

MAINTENANCE AND REPAIRS

■ 22. GENERAL.—In the forward areas of a theater of operations the maintenance of roads may present great difficulty to the corps and division engineers. Shortage of transportation, deficiency of equipment, and, above all, a lack of time may combine to make it impossible to undertake any new road construction or even to carry out repair and maintenance work except of the simplest kind. Such conditions may be assumed as normal for the forward areas in a war of movement. Where such situations exist, road maintenance will ordinarily be reduced to emergency repairs, ditching for drainage, and to spreading by shovel the gravel hauled from local pits. A shortage of transportation will often make it impracticable to secure a sufficient supply of proper patching material, and will therefore require the use of material near at hand that would not be considered suitable in civil engineering practice. The following paragraphs should be read with the above statements in mind. Maintenance must usually be done so as not to interfere with traffic.

■ 23. ORGANIZATION.—*a. Maintenance.*—In war, more than in peace, the life of a road depends upon thorough maintenance and the proper organization and equipment to effect it. The size of force employed upon maintenance will depend upon the nature of the traffic, its intensity, and the character of the roads. There are two systems of road maintenance in common use in civil practice, known as "patrol" and "gang" maintenance. In the former a definite and comparatively short section of road is assigned to a small party of one or more men who constantly patrol the section and make repairs on the theory that these should be made as early as practicable. In the latter a comparatively long section of road is assigned a large maintenance gang, which goes over the road at infrequent intervals and makes repairs. In civil practice the patrol system is now generally adopted because of the prevalence of hard-surfaced roads and the patching and repair methods required by them. The patrol is called a maintenance party. To put this system in effect, in a military situation, engineer units are assigned to the maintenance of sections of road or to the road net within a given area. The road or road net is subdivided among the working units according to the amount of road that can be covered, due consideration being given to the men and equipment available, the messing facilities for the men, and the control of the command. For continuous maintenance, under normal conditions, a combat or general service platoon should be assigned no more than about 5 miles of road; under very adverse conditions assignments should be correspondingly less. Maintenance parties may be squads or half-squads working on a shift basis within the platoon, or portions of a squad acting on a shift basis within the squad, the larger unit in either case being assigned a portion of the road. The patrol method is generally best except when the roads as a whole are of high type and/or subject to slight damage.

b. Materials.—Maintenance materials are placed in small piles alongside the roads, to be used as needed by the maintenance party. Under ordinary traffic only 2 or 3 tons of material per mile per day is necessary and this may be carried along in a truck or in wagons accompanying the maintenance party. Under heavy traffic in bad weather, and under shell fire or air bombing, the requirements in maintenance material may run to about 50 tons per mile per day.

c. Repairs.—In spite of all maintenance precautions, a road may finally reach the stage where some major repair becomes necessary. If it is an 18-foot road or wider, repairs can usually be made by treating one-half of its width at a time. On 9-foot roads it is necessary, and on 18-foot roads desirable, to detour traffic for a sufficient period of time to effect the necessary repairs. Where roads have been destroyed by enemy action, detouring is nearly always a necessity. The troops assigned to a section of road can usually make minor repairs under the maintenance system; more elaborate repairs must be made by the temporary assignment of additional means, or the utilization of the engineer reserves of the maintenance unit; and extensive repair must be treated in many respects as a road-construction job in itself.

d. Use of bituminous mixtures.—For surfacing and resurfacing, maintenance, and repair of roads of any kind, and for stabilization of sandy soils, the use of cold bituminous mixtures possesses many advantages. For surfacing and maintenance cold bituminous mixtures are prepared in mixing plants or on the road. Mixtures for maintenance and repair usually are mixed near the point of use, either by hand or with ordinary concrete mixers. Mixtures of sand and gravel or sand and crushed rock, well graded, are combined with a bituminous binder of asphaltic road oil, emulsified or cut back asphalt or tar. Mixing plants consist of means of storing, drying, and mixing the aggregates and for adding and mixing the bitumen with the aggregates. For both plant mixes and road mixes it is desirable that the bitumen be warm before mixing, as warming makes the bitumen more fluid and free flowing. Mixing plants vary from complete asphalt plants of civilian practice, with capacities up to 200 tons per hour, to a concrete mixer, a pail, a few barrels, and an improvised aggregate drier if the aggregate is wet. An improvised drier can be made from an old corrugated iron culvert pipe or some similar metal tubes or housing in which a fire can be built and the aggregate dried by piling it over the heated pipe. Plant mixes are hauled to the place of use, dumped, evenly spread to the desired thickness but not exceeding 3 inches per layer, and are then compacted by rollers and by traffic. Plant mixed material also can be dumped in piles along roads for use up to 3 or 4 months later as maintenance and repair material. Road mixes are made by blade graders and truck-drawn bitumen distributors. The distributors sprinkle the bitumen in proper quantity over the aggregate which has been hauled in and evenly spread over the road surface. The aggregate should be reasonably dry before the bitumen is applied. The blade graders then blade the aggregate and bitumen into windrows and back again to an even spread over the road. This process is repeated until the aggregates and the bitumen have become thoroughly mixed. Traffic usually will provide the compaction necessary. The total thickness of such a road-mixed surfacing can be increased to the desired depth by successive layers made as above described. Satisfactory road mixes cannot be made during rainy weather or with wet or frozen aggregates. Stabilization of sandy soils is carried on by road mixing either with or without addition of coarse aggregate, depending on the soil encountered.

■ 24. REPAIRS IN FORWARD AREAS OF COMBAT ZONE.—*a. Damage.*—An enemy in retreat will do all the damage he can to the road system, and this must be counted upon in addition to that resulting from shellfire, bombing, and use. The amount of damage encountered will depend, of course, upon the military situation, being usually greatest in the case of a withdrawal or retirement from a stabilized situation. In a forced retirement during mobile operations, the time is lacking to undertake any great destruction. In the time available, the enemy may destroy sections of a road by blowing up culverts and bridges and may effect damage to the roadway itself, especially at crossroads and road junctions and in towns. He may also fell trees or poles across the road, and effect the demolition of buildings located alongside. The problem confronting the military engineer is to get traffic forward at the earliest practicable time by the almost exclusive use of local materials. Temporary detours, bridges, and culverts are constructed and all obstacles removed. Some form of tread road will frequently suffice for a temporary detour. The original road is repaired as rapidly as possible, but this is secondary to the expedients necessary to keep traffic moving.

b. Removal of obstructions.—The first mission of division engineers with the advancing troops is to remove obstructions from the roads. Obstacles should be dragged aside so as to provide a passageway of at least 9 feet until complete removal can be accomplished. A similar passageway should be opened up through the ruins of towns. If the walls on only one side of the road are demolished, the road should be opened along the side which is intact. With the material available from the ruins, a curb 1 foot high should be built about 2 feet from any projections which might strike vehicles in passing. A sign should be placed at the entrance to the street, plainly visible to all, showing the available width of roadway, and entrance should be denied to all vehicles which may become stalled. Ruins likely to be shaken down by the vibration of traffic should be demolished and cleared.

c. Delayed-action mines.—In case the enemy has undertaken systematic demolitions, particular attention should be paid to vital areas and important crossroads left intact. The search for delayed-action mines and firing leads should be made systematically and cautiously by specially equipped details of engineers. The enemy may place mines with delayed-action primers which will not explode them for days or even weeks. One device for delaying firing is a percussion pin held by a wire immersed in a corrosive acid. A large mine may be placed under the roadway in a box, the lid of which is supported on pins which are bent down under traffic until the closing of the lid fires the charge mechanically. In removing old lead wires, care should be taken neither to relieve the tension nor to cause it, for the wire may hold a counterweight set to fire a primer, or it may be fired by a pull. The wires should be traced to their connection without disturbing them during the process. In addition all troops should be trained to avoid "booby traps" so arranged that the picking up of some desirable article will set off a mine.

d. Trenches.—Trenches cut across the road are relatively narrow and may be filled with nearby earth. Foreign substances, such as wood, manure, and vegetable matter, which disintegrate or rot, should not be used. When necessary, time may be saved by using sand bags. Surfacing material may be improvised from fascines, logs, planks, or masonry debris from buildings.

e. Shell and bomb holes.—A small hole of this sort may be repaired in a manner similar to a pot hole, first cutting the material out square and then refilling with tamped metal. A large hole is also cut out square and the debris removed; the earth is then thoroughly rammed, and the excavation filled level to subgrade with sand bags, fascines, timber cribs, or similar materials. Figure 8 illustrates methods of effecting this type of repair.

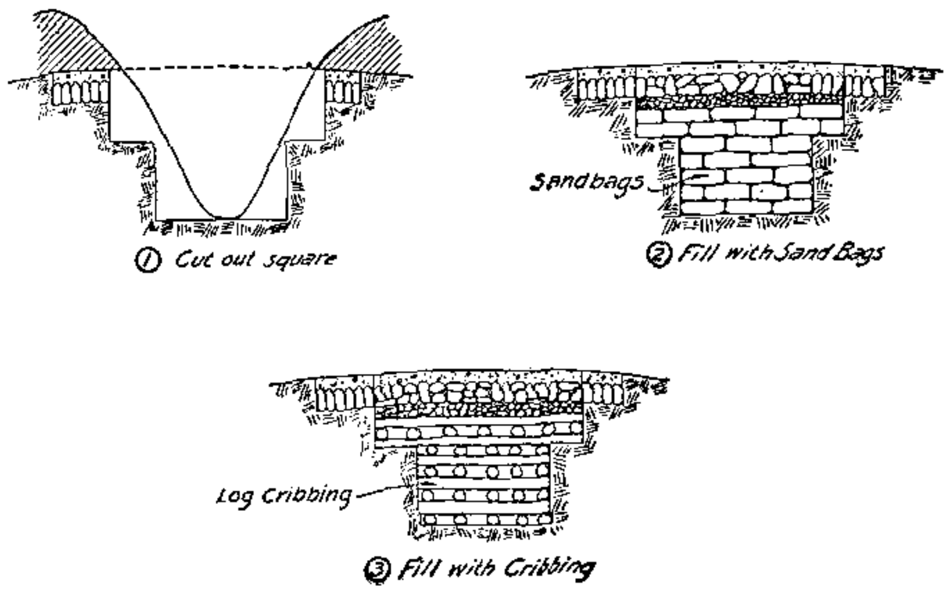


FIGURE 8.—Shell and bomb hole repairs.

f. Mine craters.—Large mine craters are generally of such size as to extend over the entire road width, being frequently over 100 feet wide and 40 feet deep. The first step is to construct a detour. The crater hole is then repaired as follows:

(1) Remove all mud and water.

(2) Fill up to within about 2 feet of the road surface with alternate layers of filled sand bags and dry, rammed earth. An alternate method is to use gravel if available. The gravel should be compacted by hand tamping as the work proceeds.

(3) Fill up flush with roadway by ordinary road construction methods.

It has been found that by placing lightly filled sand bags in craters with wire netting or expanded metal on top and then covering with 3 or 4 inches of road metal, a practicable passage for motortrucks can be made. Any available hard material may be used for filling the top portion of the crater, and the bottom part may be filled with softer material should necessity demand it. Table IV gives the relative speed of emergency repairs to mine craters:

TABLE IV.—*Repair of mine craters*

Method of repair	Man-hours required
With shovels alone	4 × volume in cubic yards.
With shovels and wheelbarrows	2 × volume in cubic yards.
With shovels and trucks where distance is not over 200 yards and number of trucks is ¼ number of men.	2 × volume in cubic yards.
With shovels and scrapers	1 × volume in cubic yards.
With standard bridge trestle and bents (trained workmen).	15 × diameter in yards.
With timbers (trees in vicinity, trained workmen)	60 × diameter in yards.
Detour of corduroy (corduroy available in vicinity)	18 × diameter in yards.
Detour of planks	9 × diameter in yards.

NOTE.—The volume of a conical mine crater is $V=\frac{\pi D^2 d}{12}$.

where V=volume of crater in cubic yards.
D=distance across top of crater in yards.
d=depth of crater in yards.
π=3.1416.

SECTION V

CONSTRUCTION, MAINTENANCE, AND REPAIR OF VARIOUS ROAD TYPES

■ 25. STANDARD ROADS.—Under this classification the following types and subtypes will be considered.

a. High-type.—Concrete, asphalt, and brick pavements; macadam roads.

b. Low-type.—Gravel, coral, shell, earth, and sand-clay roads.

■ 26. CONCRETE, ASPHALT, AND BRICK PAVEMENTS.—*a. General.*—Although these constitute, in general, the finest class of roads for sustaining continual, heavy traffic, their construction in war will be generally limited to zones of the interior. Needs for refinement, plus the special equipment and great quantities of material required, plus time consumed by the concrete in setting and curing, or by laborers in placing the bricks, or laying hot asphalt mixtures, all add up to a self-evident result. In rear areas, however, where abundant materials and equipment are readily available together with adequate transportation for hauling, the use of high alumina (quick-setting) cement concrete will reduce the setting time so greatly as to make concrete roads frequently practicable. Cold mix asphaltic concrete roads may be found equally practicable and may be used immediately after placement. Block pavement construction will seldom, if ever, be attempted during war, even in rearward areas.

b. Maintenance.—The maintenance of these roads consists largely in cleaning dust and dirt from expansion cracks, and refilling with hot asphalt.

c. *Repairs.*—Repairs to a concrete pavement are made with cement concrete or bituminous mixtures; to a bituminous road with bituminous mix; and to a brick road in the same manner or by replacing individual bricks. If extensive repairs become necessary, damaged sections must be reconstructed in accordance with desired specifications. In the maintenance and repair of concrete roads during military operations, the use of a quick-hardening cement may be desirable, but bituminous repair mixtures, if available, are preferable. A badly broken up concrete or brick road may be maintained as a rough macadam road, a binder being used when necessary. In modern practice, the edges of a concrete road are frequently made thicker than the center. This possibility should be considered in estimating the bearing power of the slab and the repairs necessary. Mud-jacking is sometimes used in civil practice to restore a settled concrete road to grade, but is not ordinarily adaptable to military maintenance.

■ 27. MACADAM ROADS.—*a. General.*—In general the word "macadam" is used to designate all roads with rock courses. "Telford macadam" indicates a road in which the base course is composed of large stones varying from 6 to 8 inches in diameter. In the non-Telford type of macadam, the large stones are omitted and crushed rock is used throughout the entire base course. In either type, the crushed rock particles of the upper layers are held together by a suitable binder such as watered stone or slag dust, bitumens, or cement. Water-bound macadam is that which results from the use of stone or slag dust washed into the interstices and rolled to compaction. A variation of this, based upon principles of expediency, obtains the interlocking of individual particles by the effects of traffic, and is hence called traffic-bound macadam. Although the same in effect as water-bound macadam (the only difference being in the method of compaction employed), in view of its wide applicability to military road construction, traffic-bound macadam will be discussed at some length in a subsequent paragraph. When bitumens are used as a binder the result is bituminous macadam; when cement is used, the name "cement-bound" is applicable. While the Telford macadam road is excellently adapted to military use, being well able to stand the continued impact of heavy traffic loads, it is nevertheless so difficult to build and so consuming of time and materials that it will seldom, if ever, be constructed in war except in rearward areas. Figure 9 shows a typical section of a Telford (knapped stone) type water-bound macadam road. In the descriptions which follow, no added reference will be made to roads of the Telford type, it being understood that such a base is equally applicable to water-bound, bitumiuous, cement-bound, and traffic-bound macadams, and that its addition merely suffices to replace a portion of the crushed rock which forms the base course.

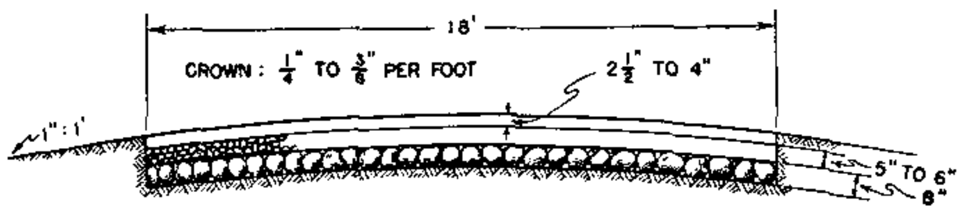


FIGURE 9.—Typical section of Telford type water-bound macadam road.

b. Water-bound macadam.—Water-bound macadam roads are generally constructed with a trench section, typical dimensions and details of which are illustrated in figure 10. Because of their cementing properties, limestone and trap rock are best suited for water-bound macadam roads, but where these varieties are not readily available, crushed gravel, slag, granite, or sandstone may be used. The size of the stone depends somewhat upon its hardness, a maximum of 4 inches being used for soft stone and 2½ inches for hard. Before the macadam can be placed, it is necessary to prepare the subgrade, which, if it does not have adequate supporting qualities, will require the laying of a subbase upon it as indicated in figure 9. The aggregate is then spread to a depth in excess of that required for the compacted course, since the loose material will be reduced about 25 percent in volume

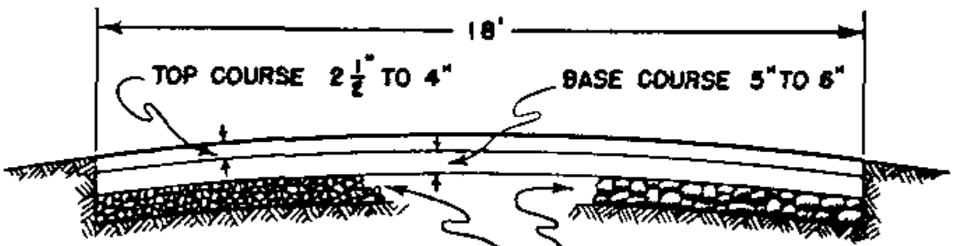


FIGURE 10.—Typical section of water-bound macadam road.

when rolled. A 4-inch layer of loose aggregate is necessary to produce a 3-inch compacted course. Rolling is started at either edge of the road, the roller traveling parallel to the edge and overlapping on the uncompacted material each trip. When the center is reached, the operation is repeated, beginning at the other edge. This should be followed by two-way diagonal rolling when time and equipment permit. After the aggregate has been thoroughly compacted, screenings are spread uniformly over the course by mechanical spreaders or by hand. These screenings should be so dry that they will readily sift through the course and fill the voids. Again roll but now use steel brooms to sweep the screenings around and prevent the formation of compacted fines on the surface. Irregularities of the surface are corrected during this operation. Binding of the course is finally accomplished by sprinkling water upon it while adding fine, dustlike screenings. Rolling again follows, and then more brooming and sprinkling until the voids are completely filled and a wave of grout appears before the roller wheels.

c. Bituminous macadam.—The term "bituminous macadam," or "bituminous-penetration macadam," is applied to a road having a wearing course composed of macadam, the interstices of which have been filled by bituminous material after compaction on its base. Methods of preparing the subgrade and placing the courses are similar to those employed in the construction of a water-bound macadam road. If either asphalt or tar cement is used as a binder it must be applied hot; on the other hand, cut-back asphalt, cut-back tar, or emulsified asphalt may be applied cold. Cut-back asphalt is made by fluxing an asphaltic cement with a lighter distillate; cut-back tar, by fluxing coal tar or low-carbon tar with cut-back oil or light, tar flux; emulsified asphalt by emulsifying a pure asphalt. More closely graded aggregates are necessary with the cold process than with the hot, and voids in the coarse stone should be filled partially with screenings before applying the cold bituminous material.

d. Cement-bound macadam.—The principal steps in construction of a typical cement-bound macadam pavement are as follows:

(1) Preparation of subgrade and setting of side forms.

(2) Spreading and compacting coarse aggregate to relatively smooth surface.

(3) Application of cement-sand grout to wetted aggregate.

(4) Compaction of grouted aggregate.

(5) Hand finishing.

(6) Curing.

The thickness of the finished pavement should be at least 6 inches for light traffic and greater in proportion to the weight and volume anticipated. A recommended mix for grout is one sack of cement to 188 pounds of clean, dry sand (1:2 mix by weight), and enough water should be added to make the grout flow readily to the bottom of the slab and fill all voids. If sufficient cement is not available for this, stone screenings or gravel may be used to fill out in the lower courses. The top 3 inches should then be filled out with a cement-sand grout, the moisture content of which has been reduced for penetration to that depth only. If prepared expansion-joint material is not available, a satisfactory joint may be made by casting a 2-inch tapered plank with the pavement, removing it before the cement has set, and then filling the cracks with hot asphalt or tar.

e. Traffic-bound macadam.—The construction of a traffic-bound macadam road combines, in reality, stabilization of the subgrade with preparation of a hard surfacing. The granular material of the first course is forced into the more or less plastic subgrade material to increase its internal friction and thus provide supporting strength for the traffic load which is transmitted downward through superimposed layers. The material used for traffic-bound macadam may be slag, cinders, shale, shell, coral, crushed stone, or gravel, practically all of which will pass a 1- or ¾-inch ring, and 5 to 25 percent of which will pass a ¼-inch screen. Steps in the construction are as follows:

(1) Shaping of subgrade and its compaction by traffic and manipulation of a blade grader.

(2) Spreading of stone or other surfacing material in a thin layer, 1 to 2 inches thick.

(3) Compaction by traffic and smoothing by blade grader.

(4) Application of additional layers of same thickness as the first, with process of compacting and smoothing repeated until a stable crust is produced.

(5) Finishing to any desired degree of perfection in accordance with the principles of construction of water-bound macadam roads. This type of road is admirably suited both to military use and military methods of construction. Excellent use may be made in it of broken concrete as an aggregate, if a small jaw crusher can be found for breaking up the debris of shattered buildings and old pavements. Roads constructed by this method from old concrete fragments have been known to stand up many years under heavy traffic, with only minor repairs being necessary.

f. Conduct of construction operations.—To construct a macadam road with any degree of rapidity, machinery must be used to the utmost, deliveries of stone must be made in dump trucks, and the work must be so organized as to proceed simultaneously at a number of different points. Operations should overlap; grading should begin as soon as clearing has created the necessary working space, deliveries of stone should begin as soon as grading has progressed far enough to permit it, and so on. When rock delivery can be made at one point only, the time of construction is considerably slowed up. By compacting under traffic much time may be saved. The following tables are of value in planning transportation requirements. Al.hough roads of 10-foot widths will normally be standard for one-way traffic, 9-foot widths are taken as basic in tables VI, VII, VIII, and IX. Figures applicable to 10- or 18-foot widths may be obtained by multiplying (or dividing) those given in the tables by 1.11 or 2.0, respectively.

TABLE V.—*Cubic yards crushed rock loose per 100 linear yards, macadam road*

Width (feet)	Depth spread (inches)						
	3	3½	4	4½	5	6	8
9	25.0	29.2	33.3	37.5	41 7	50.0	66.7
10	27.8	32.4	37.0	41.7	46.3	55.5	74.1
18	50.0	58.3	66.7	75.0	83.3	100.0	133.3
20	55.5	64.8	74.1	83.3	92.6	111.1	148.2

Screenings are required at the rate of 0.23 cubic yard for each cubic yard loose of rolled wearing surface.

TABLE VI.—*Short tons crushed rock loose per 100 linear yards, 9-foot macadam road*

Weight, 1 cubic yard stone, loose	Depth spread (inches)						
	3	3½	4	4½	5	6	8
2,250	28.13	32.81	37.50	42.19	46.88	56.25	75.00
2,300	28.75	33.54	38.33	43.12	47.92	57.50	76.67
2,350	29.38	34.27	39.17	44.06	48.96	58.75	78.33
2,400	30.00	35.00	40.00	45.00	50.00	60.00	80.00
2,450	30.63	35.75	40.83	45.94	51.04	61.25	81.67
2,500	31.25	36.46	41.67	46.87	52.08	62.50	83.33
2,550	31.88	37.19	42.50	47.81	53.13	63.75	85.00
2,600	32.50	37.92	43.33	48.75	54.17	65.00	86.67

TABLE VII.—*Linear feet 9-foot macadam road for various sizes of loads of rock*

Weight loads (pounds)		Size load (cubic yards)	Depth spread (inches)					
Granite	Limestone		3	3½	4	4½	6	8
2,800	2,500	1	12.00	10.29	9.00	8.00	6.00	4.50
3,500	3,125	1¼	15.00	12.86	11.25	10.00	7.50	5.63
4,200	3,750	1½	18.00	15.43	13.50	12.00	9.00	6.75
4,900	4,375	1¾	21.00	18.00	15.75	14.00	10.50	7.88
5,600	5,000	2	24.00	20.57	18.00	16.00	12.00	9.00
6,300	5,625	2¼	27.00	23.14	20.25	18.00	13.50	10.13
7,000	6,250	2½	30.00	25.71	22.50	20.00	15.00	11.25
7,700	6,875	2¾	33.00	28.29	24.75	22.00	16.50	12.38
8,400	7,500	3	36.00	30.86	27.00	24.00	18.00	13.50
11,200	10,000	4	48.00	41.14	36.00	32.00	24.00	18.00
14,000	12,500	5	60.00	51.43	45.00	40.00	30.00	22.50

TABLE VIII.—*Quantity of material required for military macadam road*

Loose depth	9-foot road		18-foot road	
	Cubic yards per 100 linear yards	Cubic yards per mile	Cubic yards per 100 linear yards	Cubic yards per mile
1½-inch screenings	12.50	220.00	25.00	440.00
4½ inches	37.50	660.00	75.00	1,320.00
8 inches	66.67	1,173.33	133.33	2,346.67
Total	116.67	2,053.33	233.33	4,106.67
1½-inch screenings	12.50	220.00	25.00	440.00
4½ inches	37.50	660.00	75.00	1,320.00
Total with 2 wearing courses	166.67	2,933.33	333.33	5,866.67

TABLE IX.—*Tonnage of material required for military macadam road*

(Wt. 1 cu. yd. stone, loose, 2,600 lbs.)

	9-foot road		18-foot road	
	Tons per 100 linear yards	Tons per mile	Tons per 100 linear yards	Tons per mile
1½-inch screenings	16.25	286.00	32.50	572.00
4½ inches	48.75	858.00	97.50	1,716.00
8 inches	86.67	1,525.33	173.33	3,050.67
Total	151.67	2,669.33	303.33	5,338.67
1½-inch screenings	16.25	286.00	32.50	572.00
4½ inches	48.75	858.00	97.50	1,716.00
Total with 2 wearing courses	216.67	3,813.33	433.33	7,626.67

NOTE.—A 9-foot road of 12-inch metal requires 1 cubic yard of excavation per yard of length as trench for metal and double this amount for an 18-foot road. One inch of metal requires 1/12 as much excavation.

g. Maintenance of macadam roads.—Drainage is as important to macadam roads as to any other type. The most important consideration in maintenance, therefore, is to keep the drains and ditches open and the road surface clean. A muddy surface causes the retention of water, which then seeps slowly downward to weaken the internal bond. Similarly, thawing after periods of freezing results in a weakening of the road structure. This is due to the fact that water within the interstices tends to expand when frozen, thus causing internal cracks and separation of the individual particles, and that when melting occurs the whole structure, including the subgrade, becomes so saturated that it loses its resistance to shear. Special attention must be given to the road during this period of instability, and traffic should be restricted, insofar as possible, both with respect to weights and speed. The reconstruction of a road destroyed by thaw should not be undertaken while the subgrade is soft. Each maintenance party should be provided with a sufficient number of the following tools and equipment: hoes, road brooms, shovels, picks, road rakes, scythes, wheelbarrows, tampers, sledges, and rollers. Tar mixed with heavy oil, or asphaltic road oil, spread hot or cold on the surface, is efficacious in preserving a metaled road; if such a preparation is lacking, a thin coating of clay will be beneficial in dry seasons. Scrapings from the road, rock screenings, or even light earth may be used when clay is not available. Clay and earth coatings, however, must be removed with the advent of wet weather, both to insure safety to traffic and protect the road surface against standing water.

h. Repair of bituminous macadam roads.—Bituminous macadams are patched by digging out the material in the affected area so that the sides of the excavation are square and vertical, then refilling with crushed rock (or stone) thoroughly tamped in place, and finally pouring on enough bituminous material to fill the remaining voids. Stone chips may be added and tamped as a last step. Similar procedure is followed on all other types of macadam roads, except that clay or earth binder may be used in place of the bituminous material. It is of first importance to have the rock well graded, so that minimum voids will remain after tamping and particles will interlock. Unless more than 40 percent of the old surfacing has been totally destroyed, time will be saved and better results obtained if the destroyed portions are brought back to grade by patching methods and the entire road surface then given a layer of from 1 to 3 inches with new bituminous road-mixed or plant-mixed material. As a general principle, it is bad practice to root up large areas of old surfacing still in fairly good condition, well compacted, and resting firmly on its subgrade, even when general resurfacing of a macadam road is indicated. Good practice requires retaining undisturbed as much of the old road as possible. It will provide a much better foundation for a surface topping than any new macadam.

■ 28. GRAVEL ROADS.—*a. General.*—It is probable that many of the roads constructed in war will be of this type, since gravel can be found in natural abundance in many localities. Further, it requires little preparation prior to laying. However, roads constructed of it require considerable maintenance in dry weather and are maintained with difficulty in wet weather under heavy traffic. About 20 percent of clay or other binding material is necessary in gravel to compact it to a hard surface, and, if taken from river beds, lakes, or ocean shores, the gravel must have some such binder added to it. Gravel from natural land pits where it stands in banks will normally have sufficient binding material in it to be satisfactory.

b. Construction.—If it becomes necessary to construct a new gravel road, the preliminary work, such as staking out, ditching, draining, and preparing the subgrade, will proceed about the same as in the case of other firm surfaced roads. However, it may frequently be possible to confine the work to improving the surface of existing poor roads or to make a more or less temporary road by simply dumping the gravel on the ground surface, which has been scraped clear of mud and humus, and doing little more than improve drainage. If time exists for a more careful preparation of the subgrade and handling of the gravel, it should be used to the utmost, for the resulting road will stand up better under military traffic than one more hastily constructed. Assuming that a suitable subgrade has been prepared and that sufficient binder has been found present in the gravel, successive courses, about 4 or 5 inches thick, should be carefully laid and rolled. Stones larger than 3 to 4 inches should be removed from the first course, and none over 2 inches in diameter should be permitted in the second and third courses. The road, when completed, should be not less than 8 inches in thickness. If no roller is available, the courses may be compacted by traffic and dragged to smoothness. This requires a fair-sized maintenance gang to keep the ruts filled and prevent the undue tracking of vehicles. As a basis for estimates it may be assumed that 2,500 cubic yards of gravel will be sufficient for 1 mile of new road 18 feet wide. Figure 11 shows three types of gravel roads.

c. Maintenance and repair.—Under continuous traffic a gravel road will be maintained by the same general methods as a macadam road. When sections can be relieved of all traffic, or when the width permits, a light blade grader or a road drag may be used. Figure 12 shows a type of drag suitable for this purpose. The drag is more effective when the road is wet. The principal aims in maintenance are to keep the drainage open and to preserve the proper crown. New

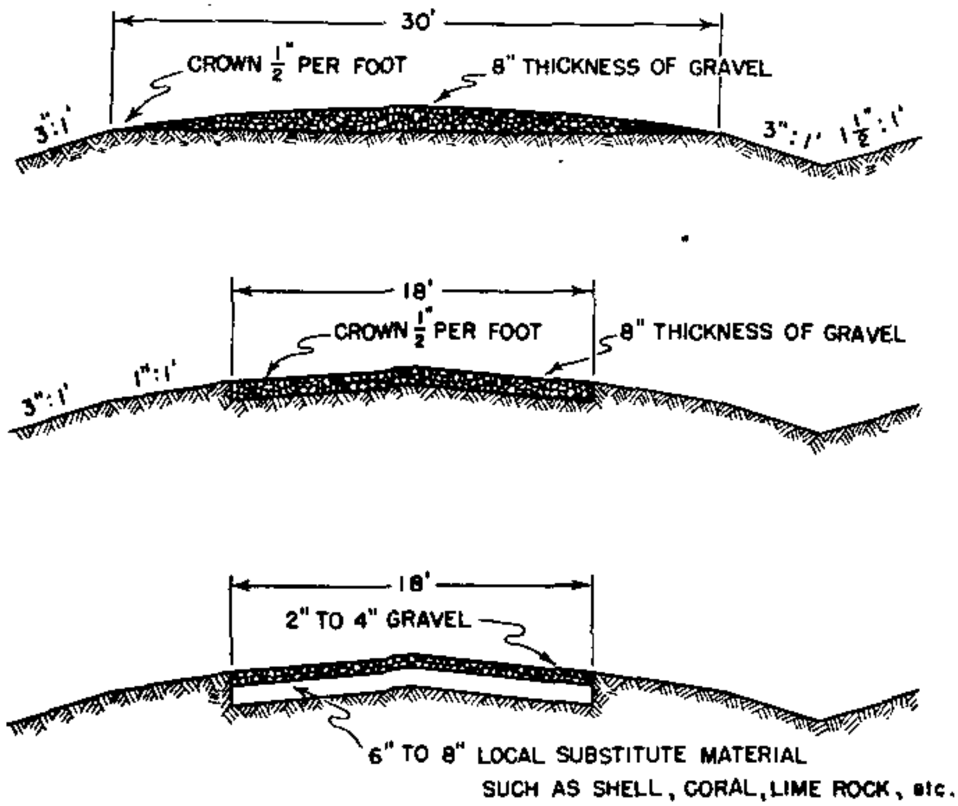


FIGURE 11.—Types of gravel roads.

gravel should be added from time to time to preserve the original thickness of the road.

■ 29. CORAL AND SHELL ROADS.—Roads may be readily built from coral and shell where they occur abundantly, methods being applied similar to those described for water-bound macadam or gravel roads. Rolling is generally necessary, particularly in the case of coral, to prevent undue wear on the tires of vehicles during the process of compaction. More breaking up of the material in place is required generally than can be accomplished by the action of pneumatic tires. Maintenance methods are simple, being fundamentally the same as for gravel roads, but, because the materials are soft, continual vigilance is necessary, particularly in wet weather.

■ 30. Sand-Clay Roads.—Where grades do not exceed 5 percent, a natural or artificial mixture of sand and clay may be satisfactorily employed in road construction. The mixture giving best results is about as follows: 5 to 10 percent clay; 10 to 20 percent silt; and 70 to 85 percent sand, 45 to 60

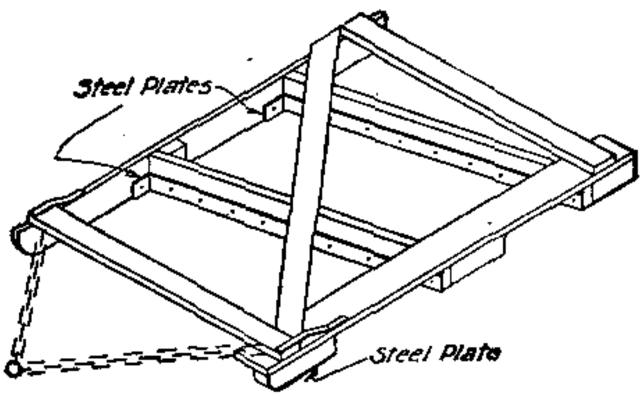


Figure 12.—Drag for gravel roads.

percent of which shall be retained on a 60-mesh sieve. The best proportions to use in any case should be determined by trial. Any one of the following methods may be adopted for construction of a sand-clay road:

a. Sand and clay may be hauled to the site separately, spread in separate layers, and then mixed.

b. Clay may be deposited on a sand subgrade and the two materials mixed.

c. Sand may be spread on a clay subgrade and mixed with the material composing the subgrade.

A trench section may be used for any of the three methods described. When method *a* is employed, a trench is first formed with a blade grader, and the bottom layer, which may be either sand or clay, is spread. Upon this layer a top layer of the other material is spread so that the completed depth will be 10 to 12 inches. Mixing is effected by plowing and harrowing the materials until a uniform consistency is obtained, after which the surface is bladed to the desired section and compacted. A bituminous seal coat composed of sand and bitumens reduces maintenance greatly.

■ 31. EARTH ROADS.—When sand, clay, or gravel are not available as materials for construction, a road suitable for light traffic is frequently obtained by grading the natural soil surface and effecting necessary drainage. The result of this is to produce a road which will serve moderately well in the immediate emergency, especially in dry weather, and upon which rock, gravel, or other material may be placed at a future time. On occasions soil of better character may be hauled in, spread upon a prepared subgrade, and then harrowed and rolled to produce a surface for traffic. The great weakness of earth roads is their nonresistance to rutting under heavy traffic, especially in wet weather. Once formed, the rut collects additional water to saturate the adjacent soil and the passage of each vehicle makes a bad situation worse. By making the road from 24 to 30 feet wide and controlling the traffic over it to prevent tracking, much damage can be avoided. Maintenance, in general, is effected by continual employment of blade graders and road drags to smooth out the irregularities. A road suitable for light traffic can often be achieved by spreading portland cement upon the surface of an old earth, gravel, or crushed stone road, harrowing it into the surface, watering, and rolling. The result is a road of the stabilized type which will be next described.

■ 32. STABILIZED ROADS.—*a. General.*—All good roads, in effect, are stabilized roads. Stabilization means that voids in the materials comprising the courses (or subgrade) have been reduced to the maximum degree by the addition of proper mineral or chemical admixtures and that the particles are bound by water film, bituminous materials, chemical admixtures, or mechanical friction in some suitable way. In the case of graded soil roads stability may be produced by adding sufficient quantities of coarse and fine mineral aggregates of proper grading and character; in the case of fine-grained soils it may be better to add water-insoluble binders such as bitumens or portland cement. It is usually advisable to cover the stabilized soils with a thin bituminous wearing surface to protect against abrasion.

b. Properties of stabilized soil.—Individual soil particles should be so graded and seated that stability is produced by an internal bond, due to interlocking of the particles and to cohesion resulting from the water film. Active capillary movement serves to prevent an accumulation of moisture in the underlying soil and to supply a desired water film in superposed layers. Sufficient cohesion must be provided by the binder to hold sand and silt particles together when the moisture content has been reduced in dry weather by evaporation. Excess water is, of course, equally undesirable, since the road must be designed to preserve a suitable moisture balance under varying conditions of climate.

c. Admixtures for stabilization.—Various admixtures and the means by which they effect the stabilization of soils are—

(1) Mineral aggregates so graded as to reduce voids or to provide the necessary water-resistant materials and mechanical stability.

(2) Deliquescent chemicals (calcium and sodium chloride) to provide moisture for compaction by traffic and to retain moisture.

(3) Primers and fillers (soaps, stone dust, and slag) to increase adhesion between mineral constituents and the chemical or bituminous admixture.

(4) Neutralizers (limestone dust, slag, and hydrated lime) to prevent the loss of stabilizing chemical in acid soils.

(5) Water-insoluble binders such as cement to hold the soil particles together and prevent volume changes. In clay soils sand may be added, and in sandy soils clay may be added.

d. Stabilization with mineral aggregates.—The aggregate used as an admixture for stabilization should consist of sound particles of gravel, crushed stone, or slag, graded in size from 1 inch to dust. If particles greater than an inch are used, they should constitute less than one-tenth of the total admixture. The desirable gradation of particles is seldom approachable in military road building, due to the facts that materials must be taken from nearby sources, and that laboratory control tests are precluded either by lack of time or equipment, or both. By making best use, however, of available materials and mixing them according to judgment and experience, any road can be generally improved. Certain indices have been established to serve as guides to the plasticity and firmness of soils, but these are determinable only by laboratory procedure. Lacking specific criteria, practical tests may be devised to assist in determining the best proportions of materials and the water ratios. One simple test is to fill a small box part full with material from the subgrade and adding available aggregates in varying proportions, mix, tamp, and test for compaction. The latter may be done by probing, by weighing a sample, or by visual examination. The water content may also be varied until best results are obtained. Such methods, of course, are crude, but the information obtained by them will frequently aid normal judgment and common sense to such a degree that a good road will result from one which otherwise would be impassable. When sieves are available for screening mixtures of native subgrade material and aggregates, they should be so used. The following gradation of particles is desirable in the final mix:

Passing 1¼-inch screen	100 percent.
Passing ¼-inch screen	50–80 percent.
Passing 40-mesh screen	20–40 percent.
Passing 270-mesh screen	5–20 percent.

The percentage passing 270-mesh should not be more than 65 percent of that passing 40-mesh. If the facilities of a soils-testing laboratory are available, they should be employed, along with the services of the personnel pertaining thereto. The details of soils-testing procedure are too many and complex to be described in this manual.

e. Construction of a stabilized road.—After materials of the subgrade and aggregate have been tested and a mixture determined, the subgrade is brought to proper grade. If the materials are to be mixed on the road surface, the subgrade soil is bladed to the shoulders and left in windrows. The new material is then hauled in and mixed with the soil of the subgrade by blading and harrowing. An alternate method is to set up a mixing plant in the vicinity of a convenient gravel pit or other source of supply and haul the materials, already mixed in proper proportions, to the road for spreading to desired depths.

f. Maintenance and repair.—Stabilized soil roads are kept in condition by adding new material from time to time, by giving proper attention to drains and ditches, and by using drags and graders as necessary to smooth the surface and preserve the crown. A road drag may be made of split logs, railroad ties, or sawed planks, as shown in figure 13.

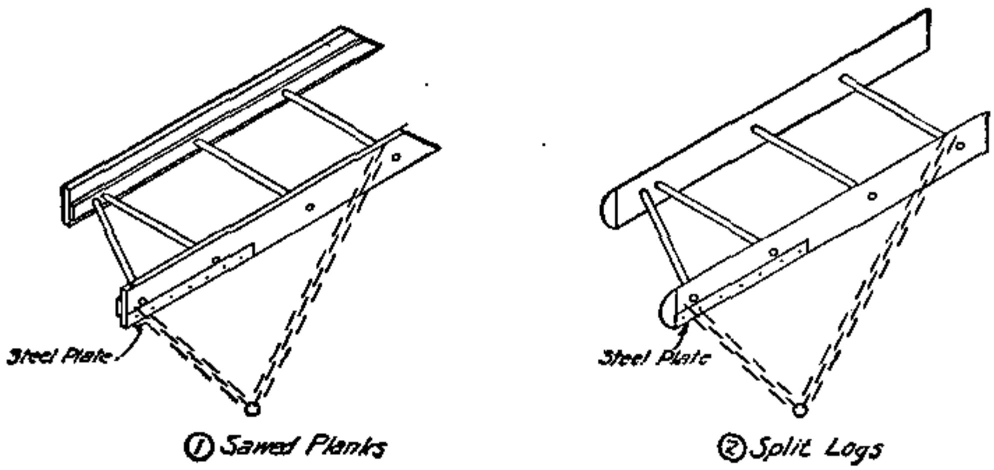


FIGURE 13.—Drags for earth roads.

Logs should be split fairly straight, although a twist of 4 inches is allowable. The drag should be light so that the driver, as he rides standing, may, by shifting his position, cause the drag to cut or deposit material as he chooses. A platform for the driver may be made of boards fastened to the bars connecting the logs. The metal plate projects one-half inch below the log at the forward end of the drag and is flush with the log at its center. The chain is long enough to allow a considerable amount of adjustment in order to make the drag cut as desired. The purpose of the drag is to increase the crown of the road and make the surface smooth by filling in ruts and holes with the material removed by the drag from high points, thus also hastening the drying out of the road. On uncrowned or poorly crowned roads, its use is advisable, but the results are not so good as on a road with a curved crown. It is intended for use on earth and sand roads, and not on macadamized or stony roads. Dragging should take place after a rain but not until the material has dried sufficiently to be no longer muddy. The drag should always be used so that the portion shod with iron is in front next to the ditch. The doubletrees or tractor cable should be so attached to the chain that the drag will make an angle of from 45° to 60° with the center line of the road. It should be remembered that the longer the chain the more the drag will cut, while the shorter the chain the less it will cut.

■ 33. IMPROVISED OR HASTY ROADS.—Under this classification will be discussed those roads which are generally constructed to meet the exigencies of a single, particular situation. Types commonly employed in military operations are plank, corduroy, tread, and wire-mesh roads, and trails.

■ 34. PLANK ROADS.—*a. General.*—When a plank road to sustain motor transportation is built, materials and their dimensions should conform to standard commercial practice. Hardwoods are best so far as maintenance is concerned but are not always plentiful, and are expensive and difficult to work and handle. Yellow pine is an entirely suitable material. Floor planks, 3 to 4 inches thick, 10 to 12 inches wide, and 10 feet long are desirable. Experience shows that an initial crown of 4 to 6 inches in the center of an 18-foot road or 2 to 3 inches between edges of a 9-foot road is essential; in the wider road the crown is finally adjusted to 2 or 3 inches. Floor planks should be spiked to stringers; nailing may be done in emergency, but will not hold, will split hard plank, and should be followed by spiking. If a plank road is to be widened later, care must be exercised so that this will be feasible; in some cases it may be found desirable to make two separate roads. The foundation must be shaped to a plane surface so as to provide a good even bearing for the stringers. The stringers settle into the subgrade and the roadway planks finally bear on the ground between them. It is therefore important to have the subgrade smooth so that settlement will not loosen the planks from the stringers. Corduroy or fascines may be used for foundations where the ground is soft.

b. Construction.—The following are steps in the construction of a plank road to sustain motor transportation:

(1) Clear and grub the right-of-way.

(2) Stake out center line.

(3) Stake out side ditches, leaving a shoulder 4 feet wide on each side of the roadway.

(4) Grade the foundation so as to provide a 4- to 6-inch rise at the center for an 18-foot road, or 2- to 3-inch rise on one side for a 9-foot road.

(5) Lay the stringers, lining them up carefully in regular rows on about 3-foot centers and breaking joints.

(6) Lay floor planks close together, bore ⅜-inch holes for spikes, and spike planks with one spike to every stringer. Stagger spikes.

(7) Spike guardrails, with 12-inch gaps between, on each side.

(8) Place pickets at 15-foot centers.

Figures 14 and 15 show cross sections of plank roads, all of which are suitable for motor transportation.

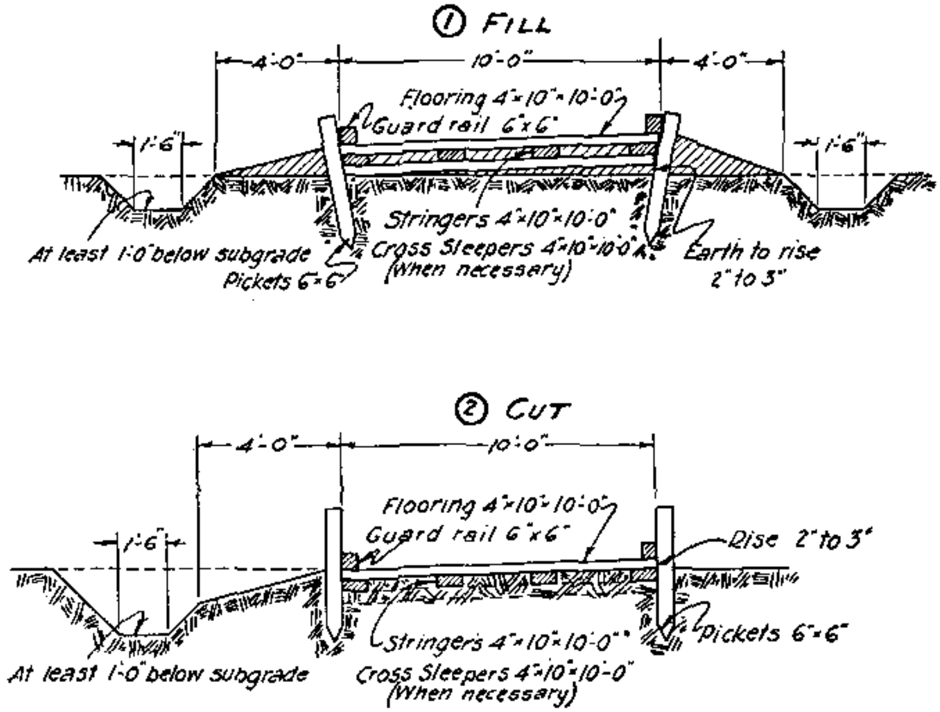


FIGURE 14.—Plank road for motor transportation, fill and cut.

c. Time and materials required for construction.—The time factor in the construction of a plank road, as of any military road, is so dependent upon a number of different conditions that no hard and fast rule can be laid down. Under good conditions it is estimated that 30 men can construct about 100 yards of 9-foot plank road, exclusive of ditches, in one 8-hour day.

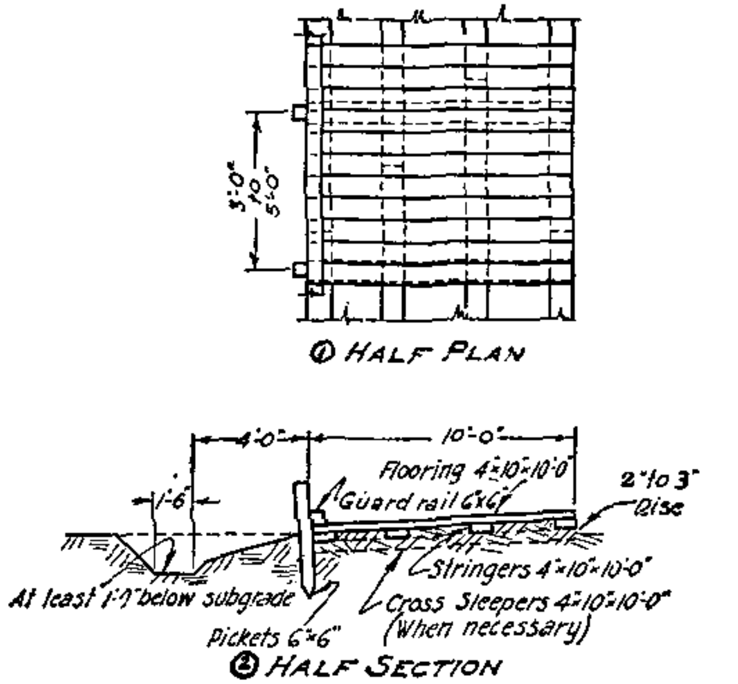


FIGURE 15.—Plank road for motor transportation, plan and section.

TABLE X.—*Plank road—data for a 9-foot road for motor transportation*

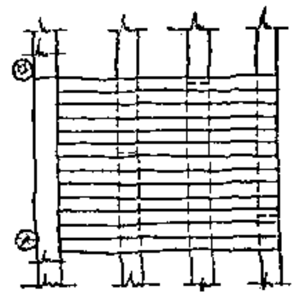
Item	Per 100 yards			Per mile		
	Number	Tonnage	Number 1½-ton trucks	Number	Tonnage	Number 1½-ton trucks
Pickets, 6 inches by 6 inches by 4 feet	40	0.8	0.5	704	14.0	9
Guardrail, 6 inches by 6 inches by 10 feet	55	2.8	2.0	960	48.0	32
Flooring, 4 inches by 10 inches by 10 feet	351	19.5	13.0	6,182	244.0	230
Stringers, 4 inches by 10 inches by 10 feet	120	6.7	5.0	2,112	117.3	78
Sleepers, 4 inches by 10 inches by 10 feet	75	4.2	3.0	1,320	73.3	49
Guardrails, spikes 8 inches	220			3,840	1.1	1
Floor spikes, 6 inches	1,404	.3	.3	24,728	5.5	4

NOTE.—For an 18-foot road all quantities are doubled except items 1, 2, and 6, which remain as above. Weights are based on longleaf yellow pine at 40 pounds per cubic foot. Sleepers are used only when necessary.

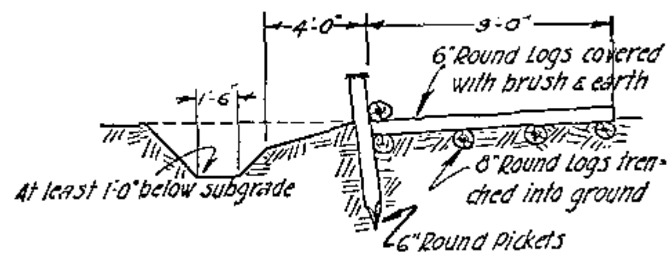
d. Maintenance and repair.—The principal precautions here, aside from drainage, are to replace broken lumber and to keep old parts, especially the floor plank, well spiked down. Sand, gravel, cinders, or similar material must be thrown on the surface in wet weather to prevent skidding. If maintenance is properly kept up by replacing broken and worn-out plank, no major repairs will become necessary. If required, traffic should be detoured and the road reconstructed as originally built.

■ 35. CORDUROY ROADS.—*a. Construction.*—Where timber is conveniently available, a corduroy road may be built over soft ground or over an existing soft road. This type of road is constructed by laying logs, split or round, crosswise of the road either on the natural surface or on longitudinal stringers. In the latter case the surface logs should be spiked to the longitudinal stringers with ½-inch spikes, 8 to 10 inches long, at the rate of one per stringer. Stringers may be ballasted with stone, crushed rock, or gravel if such material is available. The logs should be of nearly the same size and should touch, butts and tips alternating. If the logs are large, the spaces may be filled with smaller poles. The bottom tier of logs should be evenly bedded, should have a firm bearing at the ends, and should not ride on the middle. The filling poles should be cut and trimmed to lie close. If the soil is only moderately soft, the logs need be no longer than the width of the road; in soft marsh it may be necessary to make them longer. The greatest single objection to corduroy roads is in the roughness of the surface presented to traffic. This may be overcome to some extent, however, by supplying a covering of hay, straw, tall weeds, or corn or cane stalks, overlaid with earth. Such surfacing also protects the logs against excessive wear by traffic. Surface corduroy is very perishable. In marshes, where the logs are placed below the groundwater level, they are preserved from decay, and if any suitable material can be found with which to put a thin embankment over the corduroy, a good permanent road may be made. Figure 16 ① and ② shows the plan and cross section of a corduroy road laid on longitudinal stringers, and figure 16 ③ the longitudinal cross section of one laid on the natural surface.

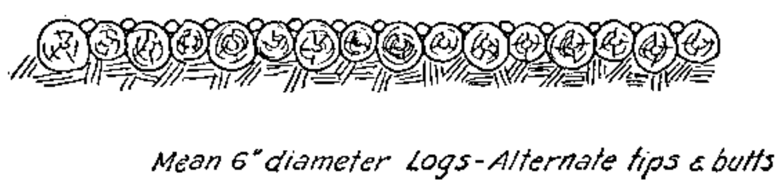
b. Maintenance and repair.—If the surface of a corduroy road is kept properly covered with brush and earth, little else is necessary in the way of maintenance except to see that the foundations are kept reasonably dry. Logs should be respiked or replaced as necessary.



① Half plan.



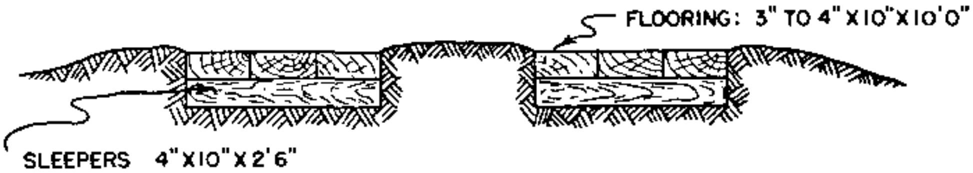
② Half section.



③ Longitudinal section.

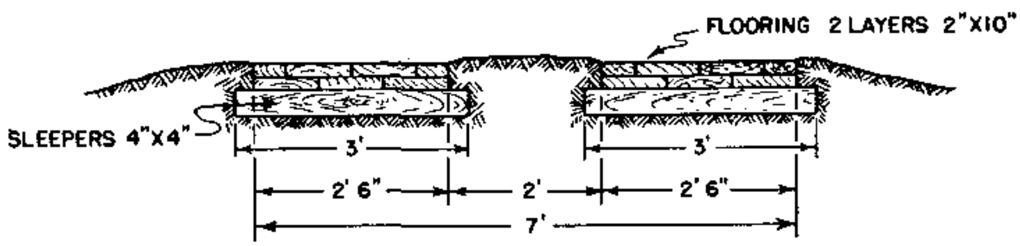
FIGURE 16.—Corduroy roads.

■ 36. TREAD ROADS.—The great advantage of this type of road is that it is quickly and easily constructed from a minimum of material. Whatever material is used, the plan of construction includes the digging of two shallow, parallel trenches about 2 feet apart, so that they will constitute vehicle treads when filled with planks, logs, corrugated pipe sectors, sand bags, rock, gravel, or concrete. Various kinds of tread roads are shown in figures 17 and 18. In the case of logs or lumber, the joints of longitudinal flooring should be broken, while with sand bags, the method of laying should be that of alternating stretchers and headers within each tread.



CROSS SECTION

① STANDARD LUMBER

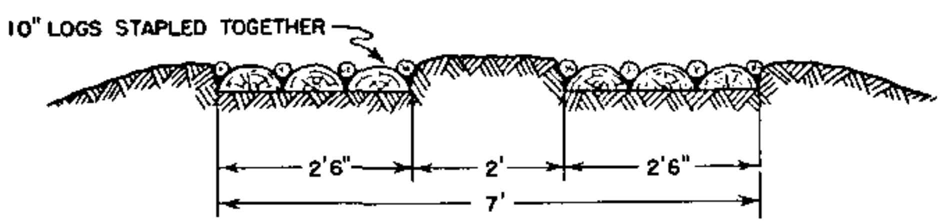


CROSS SECTION

NOTE: SLEEPERS & CURBING MAY BE OMITTED

② IMPROVISED MATERIALS

PLANK-TREAD ROAD



CROSS SECTION

CORDUROY TREAD ROAD

FIGURE 17.—Types of wood tread roads.

■ 37. Metal Mesh Roads.—Wheeled traffic often bogs down on dry, sandy soil, due to inability of the binderless sand to sustain any concentrated load. Mesh roads may be used for short periods in an emergency when it is necessary to move

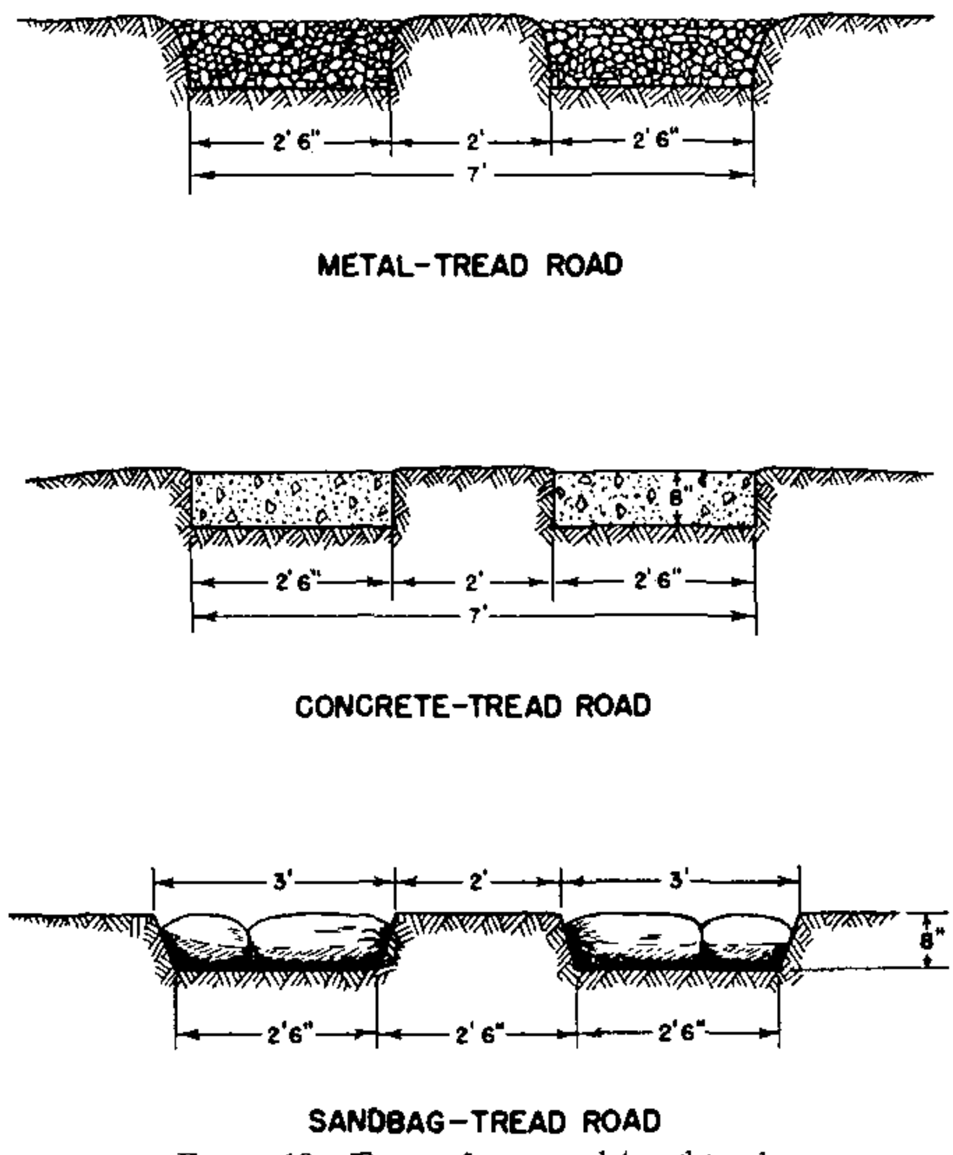


Figure 18.—Types of nonwood tread roads.

traffic over sandy beaches or similar ground. Either ordinary chicken wire or expanded metal may be employed for the purpose, the former being generally easier to obtain, while the latter is more durable. If 3-foot rolls of chicken wire are used, they should be laid in four widths with 1-foot overlaps fastened together with plain wire as laid. One layer has been found sufficient for light traffic, but three are required to sustain motor trucks through even a short period. It is desirable to lay burlap between layers of mesh and cover the whole with soil. Wooden anchoring pickets are attached with plain wire to the outer edges of the netting, and are driven at the bottom of holes about 2½ feet deep along the sides of the track at about 6-foot intervals. When the holes are filled, the tops of the pickets should be well buried to prevent tripping and damage. Traffic should never be allowed to cross a wire-mesh road at right angles. Plank or other suitable construction must be used at crossings. The wire-mesh road may be used in conjunction with brush or grass, producing a combination corduroy and wire-mesh road. Figure 19 illustrates the construction of a typical wire-mesh road. When this type of road is used, a maintenance detail must be kept continually on the job to repair broken places and to keep the wire pulled taut with the sand surface.

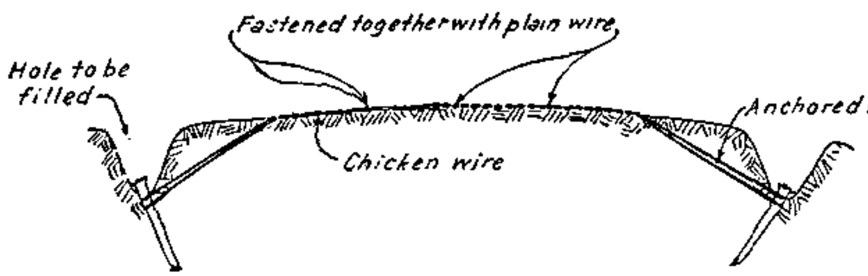


FIGURE 19.—Construction, wire-mesh road.

■ 38. TRAILS.—These are narrow paths or routes suitable for the passage of foot troops, pack animals, and light weapon-carrying vehicles. They are cleared by hand, and little work other than clearing goes into their construction, although it may frequently be necessary to provide a thin surfacing, erect small, narrow bridges, or install hand rails. Trails have a minimum standard width of 4 feet, and when cuts are made through thick growth consideration must be given to the required clearance of the traffic in order that overhanging growth may not interfere. Care should be taken, however, to avoid overcutting, thus exposing the trail to hostile aviation.

SECTION VI

PLANT AND EQUIPMENT

■ 39. QUARRY EQUIPMENT.—*a. Drills.*—Production of rock in quantity for crushing is accomplished by the use of explosives. The selection of the method of drilling is governed by the amount and nature of the work. On small jobs, where but a limited output is required, the drilling may be done by hand or with the use of organizational compressed-air tools. On large temporary jobs tripod drills are the most satisfactory. These may be run by either steam or compressed air. Either a small portable boiler or a portable compressor driven by a gasoline engine is satisfactory. In large quarries of a permanent character an air-compressor plant with a central powerhouse is the most satisfactory installation. For many jobs, especially when frequent moves are necessary, the light hammer drill, also operated by compressed air, is preferable. Portable gasoline-driven compressors capable of being transported on or by light trucks are now issued as organizational equipment. Details are given in FM 5–25.

b. Crushers.—For large output the stone is crushed by a gyratory crusher; these are also made in small portable sizes. The output of gyratory crushers permanently installed may be as high as 600 tons per hour. These are suitable for installation in the zone of the interior, the communications zone, and in certain situations in the rear areas of the combat zone. For emergency work in the combat zone the most suitable type is the portable jaw crusher with portable or knock-down bins, elevator, and screen, the whole of which may be moved by tractor or truck. These come in several sizes, with output varying from 10 to 40 tons per hour. Tables XI and XII present data for gyratory and jaw rock crushers.

TABLE XI.—*Gyratory rock crushers*

Size number	Dimensions, receiving spider openings (inches)		Capacity in tons per hour varying with character of rock		Horsepower for crusher, elevator, and screen	Approximate weight of crusher (pounds)
	Each about—	Both about—	Tons	To pass diameter ring (inches)		
2	8 by 22	8 by 44	5–10	2¼	12–15	10,000
3	8½ by 24	8½ by 48	10–20	2½	20–25	15,000
4	9 by 27	9 by 54	15–30	2½	25–30	23,500
5	12 by 35½	12 by 71	25–50	2½	30–50	32,000
6	12½ by 37	12½ by 74	45–90	3	40–60	44,000
7½	14 by 44	14 by 88	90–150	3½	75–125	67,500
8	19 by 60	19 by 120	130–225	4	100–150	100,000
10	25½ by 72	25½ by 144	400–600	5	175–250	180,000

TABLE XII.—*Jaw rock crushers* [1]

(Capacities in cubic yards per hour [2])

Jaw openings (inches)	10 by 16	9 by 20	12 by 20	15 by 20	4 by 40	9 by 40	18 by 38	21 by 38
Weight on skids (pounds)	4,700	9,800	9,900	10,200	8,500	14,000	29,000	30,000
Horsepower required	*18–25*	*25–35*	*25–35*	*25–35*	*35–50*	*40–55*	*60–90*	*60–90*
Ring size product in inches:								
¾	3½	7	6		14	11		
1	6	10	9	9	20	16		
1½	8	18	16	16	32	38	27	
2½	11	30	28	27		52	52	50

[1] Figures from Austin-Western.

[2] Average capacities shown may vary 25 percent, according to character of material.

c. Auxiliary equipment for crushing plant.—In addition to the crusher itself, a rock crushing plant will consist in detail of an elevator, screening equipment, and storage bins. The complete assembly of a typical semiportable plant is shown in figure 20.

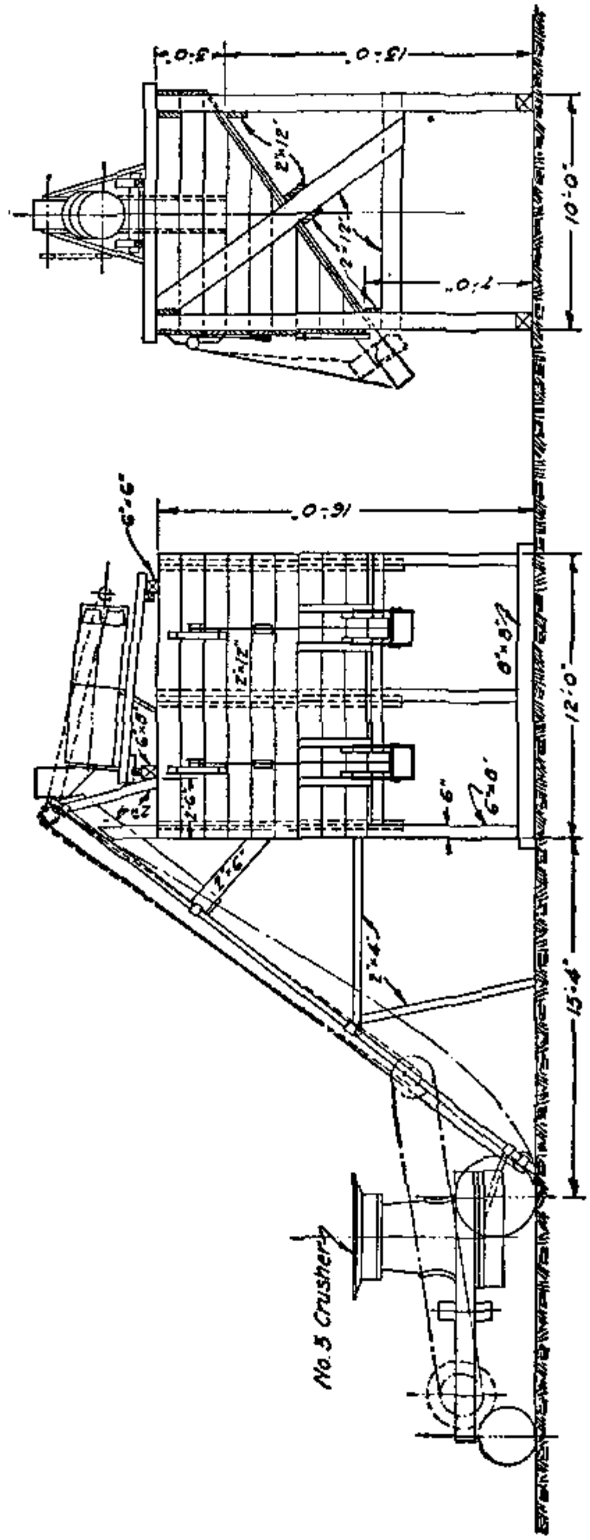


FIGURE 20.—Semiportable crushing plant.

Elevators for portable plants come in two general types, rigid and folding, and are obtainable in varying heights and capacities. The elevator frame is generally of iron pipe, strongly braced and carrying grooved rollers to support the bucket chains. The buckets are of heavy sheet steel. As all types of crushers break the stone into varying sizes, it is necessary to provide some kind of screen to provide separation of the different particles. Either the rotary-cylinder or vibratory-screen type is satisfactory, and both have perforations to permit the rocks of different sizes to fall into appropriate bins. For permanent installations the bins are usually of special design, but for portable plants standard ones are obtainable in different sizes. One type has three compartments holding a total of 28 tons, while another has four compartments holding 35 tons; the first type weighs about 4½ tons; the second, 5½ tons. Trucks are loaded from the bins by chutes. Each quarry must be provided with the necessary equipment for delivering large stone to the crushers, gravity being used to the utmost in efficient lay-outs.

■ 40. Grading Equipment.—*a. General.*—The grading equipment used in modern road construction includes—

(1) Power shovels.
(2) Plows.
(3) Scrapers.
(4) Bulldozers.
(5) Blade graders.
(6) Elevating graders.
(7) Dragline excavators.
(8) Power rollers.
(9) Motor trucks.
(10) Tractors.
(11) Crawler dump wagons.
(12) Animal-drawn dump wagons.

Scrapers, graders, and crawler dump wagons are usually drawn by tractors.

b. Power shovels.—The power shovel is the best tool for general road excavation, and is highly efficient in both rolling and mountainous terrain. Figure 21 shows a power shovel which may be operated by gasoline, Diesel, or electric motors, and which may be easily converted to use as a dragline, drag-shovel, lifting crane, skimmer, clamshell, or backfiller. This particular shovel may be moved on crawlers or mounted on a platform trailer and moved at truck speed. The ⅜- and ½-yard issue shovels will be most frequently used by military engineers in road construction, but larger plant will often become available and should be employed. Rates of digging will depend upon character of the material to be moved, skill of the operator, depth and accessibility of the cut, length of swing necessary, and a number of other factors, including

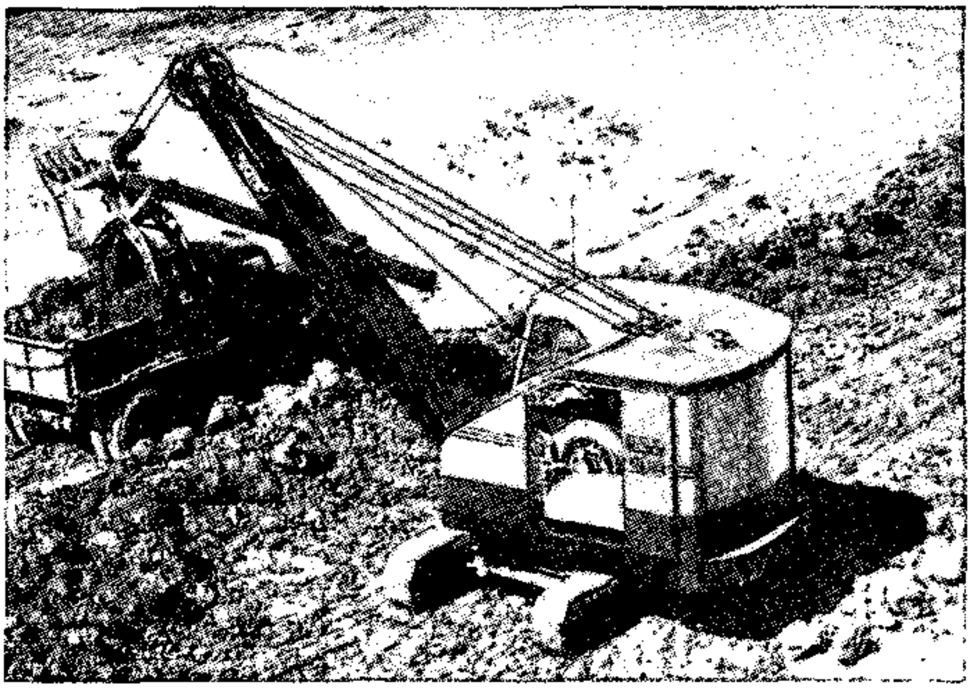


FIGURE 21.—Power shovel loading dump truck.

organization of the work and type of equipment used for hauling. The following may be taken as average rates for digging in medium soil by an experienced operator: ⅜-yard shovel, 60 cubic yards per hour; ½-yard shovel, 78 cubic yards per hour; ¾-yard shovel, 95 cubic yards per hour. These rates will be materially decreased in tough digging, such as in hardpan and when the cut is exceptionally shallow. In fact, the rate with a 6-inch cut will be only about half of that with a cut of 18 inches. It should also be remembered that the above figures do not take account of breakdowns or other similar time losses by which they may be reduced as much as 25 to 30 percent.

c. Plows.—The gang plow, animal or tractor drawn, is adapted to the breaking up of ordinary soil and even relatively stiff clay. For tougher materials, such as impacted gravel, hardpan, or macadam, the rooter plow should be used behind a tractor or power roller. Figures 22 and 23 show a gang plow and rooter plow, respectively.

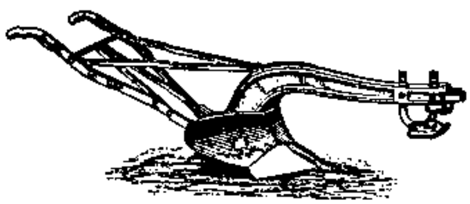


FIGURE 22.—Gang plow.

FIGURE 23.—Rooter plow.

d. Scrapers.—To combine the work of shallow excavation with that of short-haul moving, scrapers may be efficiently employed. The drag or slip scraper, illustrated in figure 24, is the usual form and is obtainable in sizes of from ¼ to ½ cubic yard capacity. It is used extensively for hauls up to 100 feet. The fresno scraper, shown in its simplest form in figure 25, delivers from ½ to 1 cubic yard of material to distances of 300 feet. Both the slip and the fresno scraper may be drawn by mules or horses as well as by trucks or tractors. An adaptation of the latter scraper, known as the rotary fresno, is generally hauled by a tractor and, by means of a single trip lever, can be made to load, carry, dump, and spread the material as required while continuing in motion. The capacity of rotary fresnos ranges from about ½ to 2½ cubic yards. The wheel scraper (fig. 26), similar to the drag scraper, is generally drawn by tractors, and is used where the haul is from 300 to 1,000 feet. The capacity of a two-wheel scraper is from ⅓ to ½ cubic yard, but four-wheeled scrapers are obtainable in capacities ranging from 1 to 1½ cubic yards.

e. Bulldozers.—For leveling areas and moving dirt short distances, bulldozers are frequently used. These consist of heavy moldboards attached to the front of tractors in such a way that the material may be pushed ahead and deposited as desired by raising the moldboard. When the moldboard is inclined to the direction of movement, the device is known

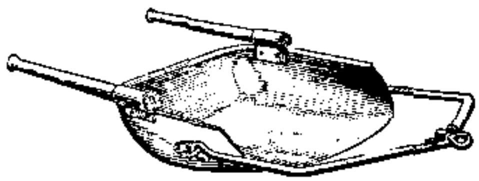


FIGURE 24.—Drag or slip scraper.

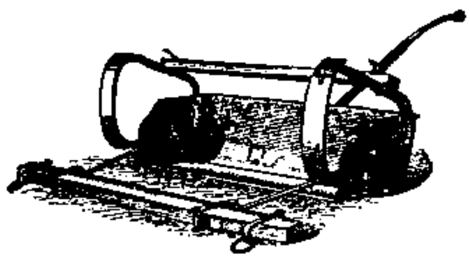


FIGURE 25.—Fresno scraper.

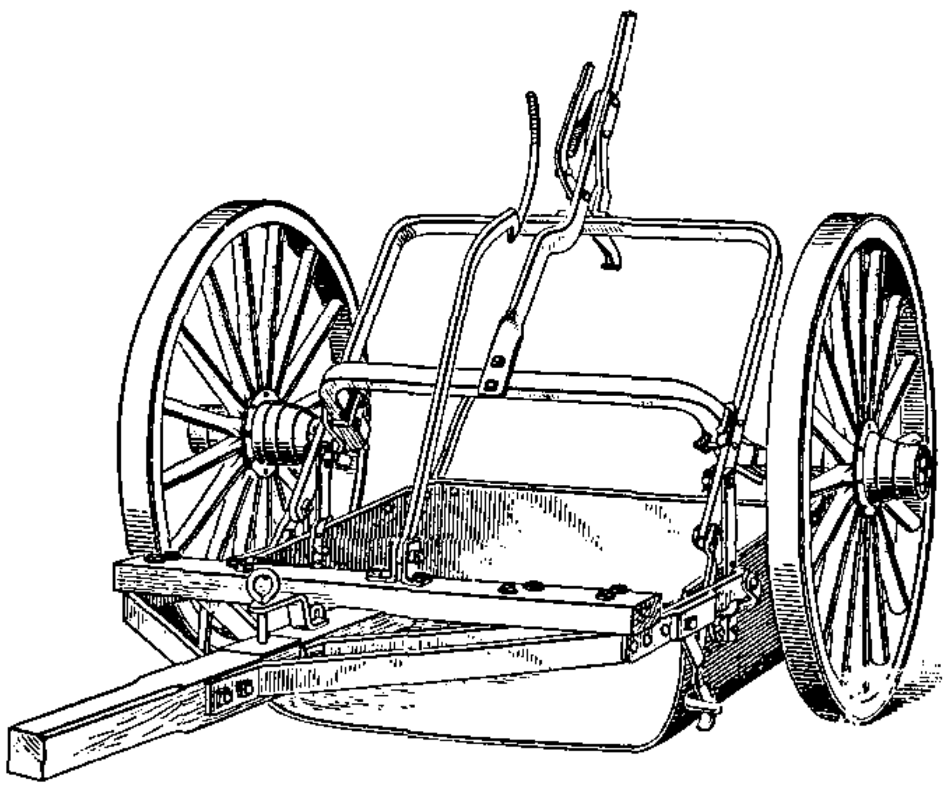


FIGURE 26.—Wheel scraper.

as an angledozer. Table XIII gives the cubic yards per hour (compact measure) that can be moved by a bulldozer powered with a 60-horsepower tractor on different slopes with varying lengths of haul. The figures can be made to apply to bulldozers of other sizes by applying a suitable factor: for example, 0.75 in the case of 45 horsepower or 1.60 in the case of 95 horsepower. The line drawn across each column indicates the economical limit of haul for the various rates of grade.

TABLE XIII.—*Cubic yards per hour (compact measure) moved by 60-horsepower tractor and bulldozer*

Length of haul in feet	Rate of grade percent uphill			Level	Rate of grade percent downhill			
	15	10	5		5	10	15	20
50	32.6	49.0	65.3	81.6	114.0	146.0	179.0	212.0
100	20.1	30.1	40.2	50.2	70.3	90.4	110.5	130.6
150	14.0	21.2	28.3	35.3	49.3	63.5	77.5	91.8
200	10.8	16.1	21.6	26.9	37.7	48.5	59.1	69.9
250	8.5	12.9	17.1	21.5	30.0	38.6	47.3	55.8
300	7.2	10.6	14.2	17.8	24.9	31.9	39.1	46.1
350	6.0	9.0	12.0	15.0	21.0	26.9	33.0	38.9
400	5.2	7.7	10.2	12.9	18.1	23.1	28.4	33.5
450	4.5	6.7	8.9	11.2	15.7	20.1	24.7	29.0
500	3.9	5.8	7.8	9.8	13.8	17.6	21.7	25.5
550	3.5	5.2	6.9	8.7	12.2	15.6	19.2	22.5
600	3.2	4.6	6.1	7.8	10.9	13.9	17.1	20.1

f. Blade graders.—Where longitudinal hauling is negligible and the work of grading is limited to shaping the roadway and preparing side ditches, a piece of equipment known as a blade grader, or blader, is used extensively. This consists essentially of an adjustable steel moldboard, or blade, mounted on a frame that is either self-propelled or drawn by a tractor. The operator can set the moldboard at any desired height and angle relative to the road surface and can thus dress the surface to the required crown. Power graders are provided with either crawler or wheel drive.

g. Elevating graders.—In this type of equipment, adaptable to uniform soil and flat ground, the blade cuts into the earth, lifts the soil, and deposits it on a moving belt, which in turn carries it to a chute, through which it is dumped beyond the edge of the road or into a truck or wagon following alongside. The equipment operates while moving continuously along the road, and when hauled by a tractor will excavate from 700 to 1,000 cubic yards of material per day.

h. Dragline excavators.—These will be seldom employed in connection with military road construction, being mainly suited to building up embankments from side borrow pits. The equipment resembles a power shovel, but instead of a shovel operating on a rigid arm from the boom, a bucket is suspended from the end so that it can be lowered into place and redrawn toward the operator's cab by a cable therefrom. By this operation a cut is made and the earth picked up; by swinging the cab and boom, the earth can then be deposited where desired.

■ 41. HAULING EQUIPMENT.—*a. Motortrucks.*—These constitute the prevailing means of transportation available to an engineer unit and will be almost exclusively used in military road construction. Dump trucks of 1½ yards' capacity will form the bulk of transportation on almost any job within the theater of operations.

b. Animal-drawn wagons.—These may be used to supplement truck hauling whenever they are obtainable. Care must be taken, however, to see that the speed of trucks is not restricted by working them over the same routes that the animals are worked on. It is desirable to provide separate loops for each class of transportation.

c. Tractor and crawler wagons.—Civil practice makes large use of heavy hauling equipment consisting of tractor-drawn wagons or "buggies" mounted on crawlers or large pneumatic-tired wheels. In the military service these will be available only as found and their employment, therefore, cannot be counted upon. It goes without saying that the military engineer, in this as in all other work, must make full use of the tools, plant, and equipment coming into his hands.

■ 42. ROLLING EQUIPMENT.—Rollers are used to compact fills and to smooth the roadbed upon which the surfacing material is placed. These come in many sizes and designs, ranging from a single cylinder to the so-called three-wheeled roller, which has a wide wheel in front and two narrower ones in rear. The rollers may be filled with concrete for ballast or may consist of empty cylindrical wheels, which may be filled with water as desired. Sheep's-foot rollers are provided with tamping feet to aid in applying greater unit pressures and kneading the soil particles into uniform compactness. These latter types are generally hauled by tractors, while the three-wheel and tandem roller are self-propelled.

■ 43. SCARIFIERS.—The difficulties of breaking up packed surface material or paving are largely overcome by the correct use of scarifiers. These are heavy machines, resembling a narrow but exceedingly strong harrow; the teeth are set with a forward slant so that they will enter and rip up the paving. Their use is limited to the repair of roads and streets. They are especially adapted for renovation where the surfacing material only is to be disturbed and where the subgrade is to be left intact. On account of the heavy work to which they are subjected, they must be strongly built. They are ordinarily drawn by tractors or are fitted to road rollers.

■ 44. SNOW AND ICE REMOVAL EQUIPMENT.—The following equipment is in general use for the removal of snow from roads:

a. Road grading machines and scarifiers.
b. Trucks equipped with straight blades.
c. Tractors equipped with straight blades.
d. Trucks equipped with V-plows.
e. Tractors equipped with V-plows.
f. Rotary snowplows and sweepers.
g. Improvised substitutes, such as animal-drawn plows, tanks, improvised plows, operated by tanks, etc. Among these may be considered a road grader equipped with a special saw-toothed blade or with teeth bolted to blade to cut or score grooves in an iced surface parallel to the direction of travel. Such blades may also be used on bulldozers or similar equipment to roughen the surface and prevent skidding hazards. In summer months the same arrangement may be employed

to tear up black-top, tar, and macadam roads; for dirt and gravel road maintenance; and for eliminating washboard corrugation, ruts, hollows, and other irregularities.

SECTION VII

SUMMARY

■ 45. SUMMARY.—*a*. Do not build a new road when an existing one can be reconditioned; utilize the existing net to the fullest.

b. Drainage is vital to roads; get the water off and the rock on.

c. After drainage, three things enter into the making of a good road:

(1) A firm, dry foundation to carry the load.

(2) Homogeneous, well-knit base and intermediate courses of well-graded materials, compacted in place to distribute the load to the foundation.

(3) A top or wearing course to resist abrasive action and shed water to the ditches.

d. Do not try to maintain too many roads; a few good ones between vital points and to the front are better than many poor ones, aimlessly located.

e. Use local materials whenever possible, and to this end keep up a continual search for them.

f. Effect repairs as soon as they are needed. Steady maintenance over periods of use will save many days of work later and will result in economy of time, labor, and materials.

g. Stock-pile necessary materials along the road at intervals for use in making repairs and develop a plan for future supply.

h. Make the maximum use of road machinery and equipment, both in construction and maintenance.

i. Efficient organization with decentralization of responsibility is necessary to road maintenance. Make each man and each unit responsible for all work within an assigned area.

j. Ingenuity, energy, and determination are essential to the construction and maintenance of military roads.

CHAPTER 2

BRIDGING, GENERAL

SECTION I

BRIDGING CONSIDERATIONS

■ 46. ROLE OF BRIDGES.—*a*. A line of communications, as defined by a road or railroad, must be held intact throughout its entire length. Breaks in the line mean breaks in the system of supply and, as in a chain, the whole can be no stronger than its weakest link. Bridges afford a means of carrying the line forward across streams, rivers, gulches, ravines, or draws, which otherwise would constitute serious obstacles to the rapid movement of troops, supplies, or armaments. By their very nature they are extremely vulnerable, hence it is of first importance to protect and maintain all crossings which are subject to the present or future use of friendly troops. The need for new construction must be carefully weighed when laying out a system of communications, for if such work is excessive a relocation of the route may be indicated. Under certain circumstances it may be highly desirable to circumvent a terrain depression at the cost of a longer road to build and maintain; on the other hand, it may be possible to effect a material saving in time and labor by the construction of a suitable crossing. Consideration should always be given to the possibility of substituting for bridges low embankments with culverts, since the latter are less vulnerable to hostile aerial attacks and, in cases where relocations are possible, may be less costly in materials of construction. When the need for a bridge is definitely indicated, decisions must be made as to the type necessary to carry the anticipated loads, the permanence required in the structure, and the materials and labor available for its construction. As in the case of roads, new construction should be held to a minimum, full advantage being taken of existing structures. Also, full use must be made of locally available materials, to which end reconnaissances must be extensive and continuous.

b. Necessity for the utmost speed in bridging operations requires that every possible preparation be made for the construction of bridges that will be required in a particular operation. Information regarding spans of bridges required for the advance is necessary in order that the equipment will be suitable as to type and amount. The material required and the engineer troops necessary for the construction should be well forward in order to expedite the erection of the bridges.

■ 47. Scope of Discussion.—Bridging considerations are discussed generally in the present chapter with the purpose of providing descriptive information relative to the terms used, the types of bridges encountered, and the degree of safety required. In this chapter also types of design are treated as they apply to bridges in general, and, in a discussion of reconnaissances, special consideration is given to the investigation of existing bridge structures. Standard types of military bridges are described in chapter 3 and, lastly, account is taken of means by which the crossing of streams may be effected, in the absence of bridges, in chapter 4.

■ 48. Bridge Nomenclature.—*a. General.*—The essential, basic components of a bridge are the substructure and the superstructure. Included in the substructure, in addition to the abutments and foundations, are the supports upon which the superstructure is carried. These latter may take the form of piers, bents, or pontons. The superstructure constitutes the remaining upper part of the structure, including the stringers, flooring, stiffeners, and overhead supports.

b. Definitions.—Some of the more common, general words used in connection with the subject of military bridging may be defined as follows:

(1) *Abutment.*—The ground support of the superstructure at an end of the bridge.

(2) *Balk.*—The standardized stringers of a floating bridge.

(3) *Bent.*—An intermediate, transverse support consisting of a framework of horizontal and vertical members, usually requiring external bracing for stability. (Short pile bents do not require longitudinal bracing.)

(4) *Chess.*—The standardized floor-planks of a floating bridge.

(5) *Flooring.*—The deck covering which forms a roadway for traffic across a bridge.

(6) *Footing.*—The arrangement whereby loads from supports or bridge seats are distributed over a greater ground area as a means of reducing unit pressures.

(7) *Girder.*—A simple or built-up beam, usually of steel, designed to carry floor loads to piers or abutments.

(8) *Pier.*—An intermediate support of masonry, reinforced concrete, cribwork, or of several bents so constructed as to form an integral unit needing no additional bracing for stability.

(9) *Ponton.*—A float, often in the form of a boat, used to provide buoyance for the superstructure and imposed loads of a bridge.

(10) *Sill.*—The member of a support which rests directly upon the ground or a footing.

(11) *Span.*—The portion of a bridge between centers of two adjacent supports; alternately, the distance between such centers.

(12) *Stiffener.*—A girder, or truss, used to stiffen the superstructure and to aid in carrying the weights imposed upon it.

(13) *Stringer.*—One of a number of longitudinal members resting upon end supports and carrying the flooring.

(14) *Trestle.*—Same as a bent; often referred to as "trestle bent."

(15) *Truss.*—A compound beam, the parts of which are arranged to form one or more triangles in the same plane so that the beam will transmit roadway loads from the floor

system to the abutments or to intermediate vertical supports called panel points.

■ 49. TYPES OF BRIDGES.—Bridges may be classified according to inherent fixity (as whether they are fixed, movable, or portable); according to the number of spans (single or multiple); according to the type of supports employed; or according to the materials used in construction. Other classifications may be as to the magnitude and character of loads to be carried, and as to the general character of structure; that is, whether it is a bascule, cantilever, suspension, or ponton bridge. But even these are not all-inclusive methods of classification; the breadth of subject is such that no clear-cut cataloging and indexing are possible. Considering the matter, however, from a standpoint of what bridges are adaptable to military use, logical classifications can be made with regard to loads carried and types of support.

a. Loads carried.

(1) Foot and cart bridges.

(2) Light vehicular bridges.

(3) Heavy vehicular bridges.

b. Types of support.—It is possible to group together all fixed supports, such as cribs, piers, bents (and abutments only, in the case of simple stringer bridges) and arrive at the classification:

(1) Floating bridges.

(2) Nonfloating bridges.

The following table shows the more common types of military bridges arranged according to these classifications. Omitted from the table are such types normal to civil practice as suspension bridges, steel cantilevers, movable (lift) span bridges, railroad bridges, etc. Standard military types, included in the table, will be fully described in chapter 3.

Types of military bridges

Type	Classification	
	Floating	Nonfloating
Foot and cart	Standard footbridge equipment (model 1935) (duckboards on floats). Kapok footbridge (obsolescent) (crates filled with kapok pillows). Improvised types using gasoline drums, cans, wooden floats, or other expedients.	Simple stringer. Light trestle bents: Pile. Framed. Lashed spars.
Light vehicular	Metal pontons (model 1926, 7½-ton). Metal pontons (model 1938, 10-ton). Pontons with canvas-covered wood frames (model 1869, light ponton) (obsolete). Wooden pontons (model 1869, heavy pontons) (obsolescent). Improvised raft supports of wood or metal drums, logs, boats, etc.	Simple stringer (wood or steel). Framed trestle bents. Framed trestle piers. Pile trestle bents. Pile trestle piers. Lashed spar trestles. Portable truss girders (H–10 loading).
Heavy vehicular	Heavy ponton equipage (model 1924, 23-ton). Light (metal) ponton equipage (model 1926, 7½-ton) reinforced to carry 15 tons. Light (metal) ponton equipage (model 1938, 10-ton) reinforced to carry 20 tons. Improvised raft supports.	Demountable steel truss girder (23-ton capacity) (obsolete). Portable truss girders (H–20 loading). Simple stringers. Framed trestle bents. Framed trestle piers. Pile trestle bents. Pile trestle piers. Crib piers (wood or steel). Concrete or masonry piers.

■ 50. MATERIALS OF CONSTRUCTION.—*a. Wood.*—Except for the portable ponton and steel truss girder bridges adopted as standard in the Army, most bridges will be constructed of timbers in time of war. For this reason it is desirable that the military engineer have definite knowledge of the commercial sizes in which lumber and timber are generally obtainable. The most common cross sections, expressed in inches, are as follows:

2 x 4	2 x 6	2 x 8	2 x 10	2 x 12	2 x 14	2 x 16
		3 x 8	3 x 10	3 x 12	3 x 14	3 x 16
4 x 4	4 x 6	4 x 8	4 x 10	4 x 12	4 x 14	4 x 16
	6 x 6	6 x 8	6 x 10	6 x 12	6 x 14	6 x 16
		8 x 8	8 x 10	8 x 12	8 x 14	8 x 16
			10 x 10	10 x 12	10 x 14	10 x 16
				12 x 12	12 x 14	12 x 16
					14 x 14	14 x 16
						16 x 16

Ordinary lengths are 12 to 20 feet, lengths of 20 to 26 feet are less common, and 27- to 32-foot lengths are obtained with difficulty. In ordering lumber, bills of material are prepared to show for each item the number of pieces required, and the cross section, length, grade, and surfacing of each piece. Four pieces of No. 1 common Douglas fir, each 16 feet long, 12 inches wide, and 6 inches thick, surfaced on all four sides, would be designated:

4—6″ x 12″ x 16′, Douglas fir, No. 1 common, *S4S*

Lumber is usually sold by board feet (*FBM*=feet board measure), the unit being a board 1 foot long, 1 foot wide, and 1 inch thick. To compute the *FBM* in any rectangular timber the length in feet is multiplied by the width in feet and by the thickness in inches. Thus, in the four pieces of Douglas fir mentioned, there would be:

$$4 \times 6 \times 1 \times 16 = 384 \ FBM.$$

In general, the cross section of surfaced pieces will be somewhat less than unsurfaced pieces. Since the above dimensions are based on unsurfaced pieces, the designer should take into account the decreased area of the surfaced sections.

b. Steel.—When the span is greater than 15 feet, steel stringers are frequently used. These should be designated by standard sections, which in the case of I-beams are represented by depths of 3, 4, 5, 6, 7, 8, 10, 12, 15, 18, 20, and 24 inches and by different weights as given in manufacturers' handbooks. For the standard type, H–15, trestle bridge, suitable *CB* (car building) sections are to be stocked in depots.

■ 51. FACTORS OF SAFETY.—*a. General.*—If a structure were loaded to its ultimate safe stress, the application of any additional load would result in its failure or damage. Although, in theory at least, the structure would continue to stand undamaged until its ultimate safe stress had been exceeded, no such narrow margins are permissible in practice, for the failure or damage of structures may be attended by serious consequences, and in no case is it possible to determine exactly the ultimate strength within the elastic limit of a material or the exact loads to be imposed. Furthermore, perfect construction is not possible. The factor of safety of a material or a structure may be defined as the ratio of its ultimate safe stress, within the elastic limit, to its actual working stress. In civil practice, factors of about 2.2 and 4.0 are applied to steel and wood structures, respectively. Since safety is of relatively less importance in war than in peace and economy of materials is very important, these factors may be reduced to 1.75 for steel and 3.0 for wood in certain cases, particularly in connection with bridges in forward areas or which will be used for only a short time. Under exceptional circumstances, the factors may be reduced still more, but in such cases the bridge should be strengthened as soon as conditions permit. For bridges in the communications zone and large and important bridges in the combat zone which will be used for a considerable time, the civil factors should be used.

b. Impact.—When a load is moved suddenly upon a bridge, exceptional stresses are induced, for which, in civil practice, due allowances are made during design. These are the exceptional and momentary stresses produced by excessive strain before the material has adjusted itself to the load, and the impact produced by the momentum of the load. The former is taken care of in the factor of safety; the latter is taken care of in civil practice by an allowance therefor. In the design of military timber bridges, however, no allowance is ordinarily made for impact; and for steel bridges, including wooden bridges with steel stringers, the factor used is half that of the American Association of State Highway Officials. The formula as modified in the latter case is:

$$I=\frac{25}{(L+125)}$$

in which I is the percentage of the live load to allow for impact and L is the length in feet of the span considered. It will be seen from the formula that a factor of 20 percent is adequate in any case. Theory must be tempered with both judgment and experience when figures less than 15 percent are obtained or when loads of exceptional character are anticipated.

SECTION II

DESIGN OF BRIDGES

■ 52. APPROACHES.—*a. General.*—The following considerations are important in connection with the siting of bridge approaches:

(1) It should be borne in mind that work on the approaches will often, if not usually, be greater than the work on the bridge itself. The location of the bridge will therefore usually be very dependent on possible approaches and their condition.

(2) The center line of the road from each end of the bridge should continue straight for at least 50 yards in a prolongation of the bridge axis.

(3) Approaches should have a slight upgrade toward the bridge.

(4) Maximum use is to be made of existing roads.

(5) Approach roads should be made wide, with turn-outs or parking areas at each end of the bridge when the necessity for same is indicated.

b. Preparation of the roadway.—If the approach roads are on very bad ground and there is insufficient metal to provide a relatively hard surface up to the abutment, it may be necessary to provide an extra timber span, as shown in figure 27, or to lay a plank road upon the ground surface. Corduroying is also effective in such cases, but less desirable because of the tendency of traffic to side-slip upon it and because of its rough nature. When the approach is very firm, it may not be necessary to use any form of timber decking, but if the roadway has been excavated behind the end dam (see par. 53*e*) or if it must be built up, great care must be taken with the backfill, which should be of rock or crushed aggregate, tamped in layers about 3 inches thick. The road surface at the end of the bridge should be of broken stone or similar material laid as macadam unless a more rigid surfacing is possible. To avoid shocks and possible displacement of the bridge due to vehicles striking against its end, the road surface should be built up to about an inch above the flooring. Too high or too low a road surface at this point of juncture may decrease the life of a bridge as much as 50 percent. (See ch. 1, for methods of road construction and repair.)

c. Maintenance.—Having taken care of the approaches, it is next necessary to provide for maintenance. The tendency of all heavy traffic is to develop holes in the road pavement about 2 feet from the end of the bridge. As explained, this results in a jolting of vehicles, with an attendant increase of impact on the bridge, both vertically and horizontally. With horizontal jars transmitted to the abutment each time a truck passes, serious consequences may quickly ensue. For this reason periodic inspections should be scheduled and continuous maintenance arranged if necessary. Road materials, stacked in convenient piles at each end of the bridge, facilitate the work of repair.

■ 53. ABUTMENTS.—*a. General.*—Abutments for military bridges vary in character according to the planned permanence of the structure. Designs are based on expediency, with primary consideration usually to speed and ease of construction. Although the loads on a semipermanent military bridge may exceed normal highway loads, it is improbable that time will permit the same care of construction in the first case as in the second. Lack of time must be compensated for by increased judgment. The importance of time-saving in connection with abutment construction may be appreciated by consideration of the fact that on bridges of short span—say up to 100 feet—the construction of abutments, similarly to work on the approaches, may require as much time as the entire remainder of the work. In permanent highway construction the abutment is usually constructed of masonry or concrete. In military bridging this type of construction requires too much time. Furthermore, the military bridge is not usually designed to last long periods of time. Hence timber is the material generally used in military abutments.

b. Component parts.—A bridge abutment consists of three distinct parts:

(1) A bank seat which supports the bridge span.

(2) The connection between the bridge and approach.

(3) The retaining walls or other arrangement provided to prevent the earth from sloughing off beneath the bank seat.

c. Bank seat.—The bank seat consists usually of a bridge seat, or timber sill, upon which the end of the span rests, and a timber footing, or mudsill, which serves to distribute the load over a greater area. Both these, reduced to their simplest form, are shown in figure 27. For heavy steel bridges it is frequently necessary to place a bearing plate between the bridge span and the seat in order to distribute the load over a sufficiently large area to prevent crushing the wooden sill.

d. Construction of footings.—The following principles should be observed in placing timber footings:

(1) Set the footing course about 2 inches higher than its final desired position to allow for settlement.

(2) Do not dig too deeply into the bank. If this is done by mischance, raise the seat by planking rather than by back-filling with earth.

(3) Keep behind the natural slope of the earth, which is usually about 1½ horizontal to 1 vertical. Lacking laboratory facilities, this can be determined for practical purposes by observing old cuts and fills in the immediate vicinity.

(4) Place the pieces of the lower footing course parallel to the axis of the bridge.

(5) Place the bridge seat so that the load comes on the middle of the footing course.

(6) Fill and tamp the footing thoroughly if it is placed in a trench. Provide for drainage if it is placed on a shelf excavation.

(7) The projection area of the footing must be such that the safe bearing pressure of the ground is not exceeded. (See par. 54.)

(8) The timber must have sufficient cross section to withstand crushing and bending. (See par. 54.)

e. End dams.—After the bank seat has been built up, and the bridge is in place, an end dam of planks should be placed, as shown in figure 27, across the ends of the stringers, to which it may be spiked. The purpose of this is to keep the roadway from caving in between the stringers at the abutment.

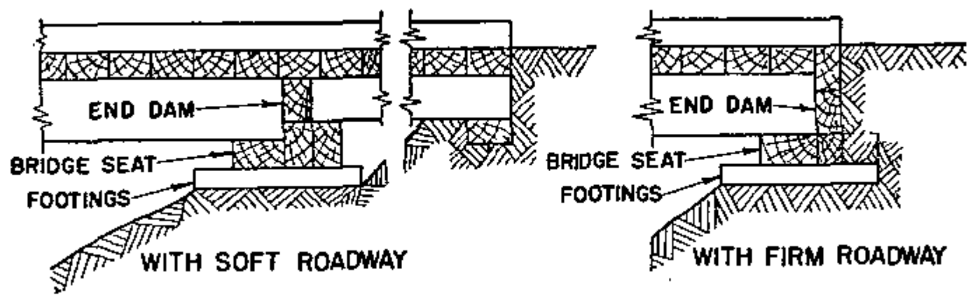


FIGURE 27.—Abutments for simple stringer bridges.

f. Retaining walls and revetments.—(1) The object of retaining walls is not only to prevent the earth from sloughing away beneath the bank seat but also to facilitate a shortening of the span. Figure 28 shows a means of employing piles and sheeting for this dual purpose, and braced frames or cribs may be similarly used. When the water is likely to rise above the base of a crib, rock ballast should be supplied, both inside and out.

(2) Revetments are frequently employed to prevent undue scour around or beneath the bank seats in times of flood when velocities are high. Such revetments may take the form of brush mats or riprap, extending from low-water level to the top of banks. If riprap is used, it is desirable to lay it on a 6-inch gravel blanket, providing time and materials are available and the bridge is to be used over a considerable period. Concrete paving is entirely satisfactory as a means of protection, but requires more time to place, and for that reason is seldom used on military bridges. When used, it should be provided with weep holes for the outward flow of water from the saturated bank after recession of flood stages. Surface

drains should be provided as a means of preventing erosion around the ends of the bank seats.

■ 54. Design of Foundations and Footings.—*a*. Add the total of live and dead loads (see par. 57) on the bridge seat to determine the pressure beneath it, in pounds, allowing

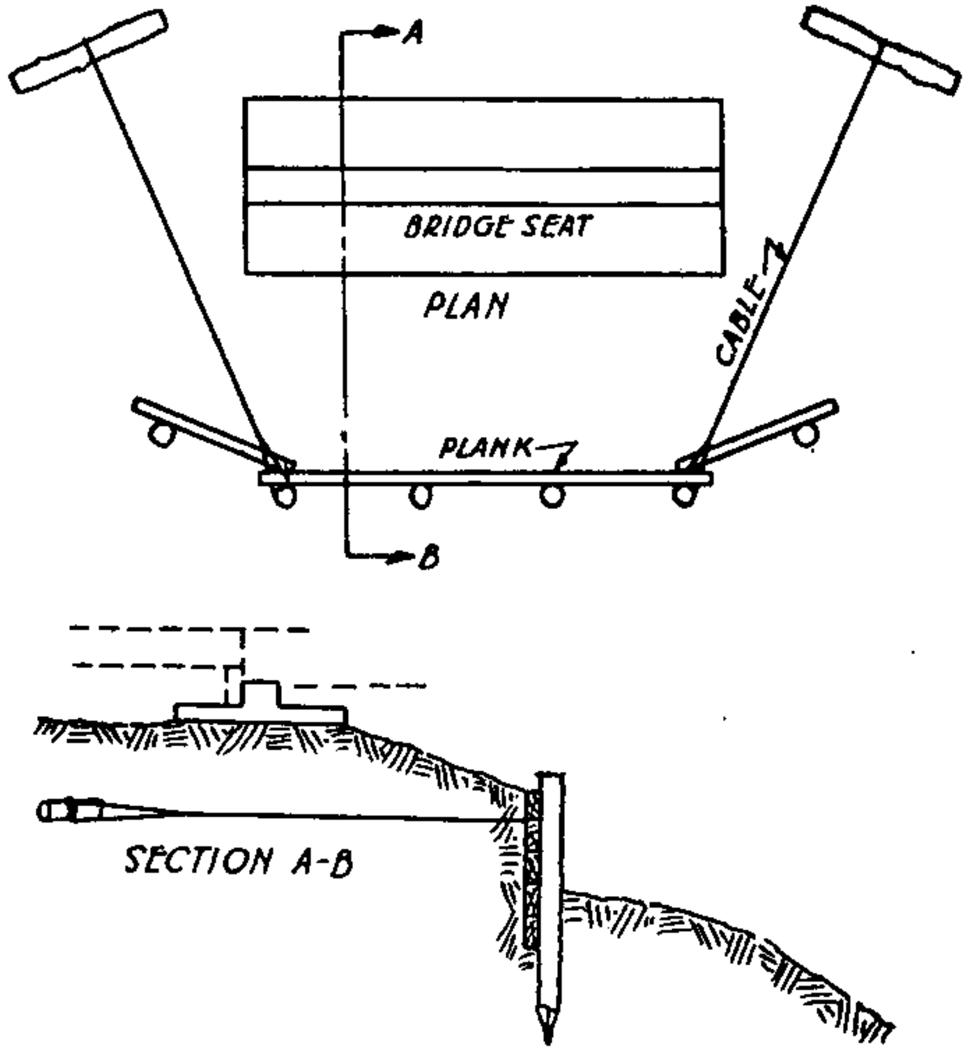


Figure 28.—Pile retaining wall.

25 percent for impact. Example: 35,000 (dead load) + 10,000 (live load) = 45,000 pounds (total).

b. Divide this figure by the unit bearing power of the soil, determined by inspection, from the following:

Soil	Unit bearing power (pounds per square foot)
Loam	1,500
Silt or clay fills, after 6 months (general)	1,500
Soft clay	2,000
Firm clay, confined sand, or gravel	8,000
Rock	20,000–40,000

Example:

$$\frac{45{,}000}{1{,}500}=30 \text{ sq. ft.}$$

The result is the required bearing area of the footings, or of the bridge seat (sill) if no footings are required. Where footings are required, it should be assumed that the bridge seat (sill) will not provide any bearing and that the footings alone must furnish the full surface area.

c. Assume lengths and widths of footings desired and compute number required. Example: For footings 4 feet long and 1 foot wide, number required $=\frac{30 \text{ sq. ft.}}{4 \text{ ft.} \times 1 \text{ ft.}}=7.5$ or 8.

d. Next test the footings against bending, by the formula:

$$t=\frac{K\sqrt{P}}{C}$$

in which K=projection in feet of the footings beyond the bridge seat or trestle sill.

C=constant, depending on material of footings, and varying roughly from 20.0 for timber to 7.0 for concrete (1–2–4 mix) with a permanent set.

P=safe pressure, in pounds per square foot, on the bottom of the footing course (or the safe bearing power of the soil).

t=thickness in inches of the footings.

Example: Assuming a timber bridge seat 12 by 12 inches length of projection,

$K=\frac{(4-1)}{2}=1.5$ feet. $t=\frac{1.5\sqrt{1500}}{20}=2.9$ inches, or 3 inches for thickness of timbers.

e. It will be seen that in any given case several solutions are possible, depending upon the widths, lengths, and thicknesses of timbers used as footings. For instance, instead of eight pieces, each 3 inches by 1 foot by 4 feet, it might be necessary to use the requisite number of 4- by 8-inch pieces, found to be nine if each is made 5 feet long. To test against bending, the following table, giving *K* of the formula in feet, is useful:

TABLE XIV.—*Safe unsupported projection (k) of timber footings, in feet*

Distributed load per square foot	Thickness of timber					
	1 inch	2 inches	3 inches	4 inches	5 inches	6 inches
¾ ton	0.51	1.03	1.54	2.06	2.57	3.09
1 ton	.44	.89	1.34	1.79	2.53	2.68
1½ tons	.36	.73	1.09	1.46	1.82	2.19
2 tons	.31	.63	.94	1.26	1.57	1.88
2½ tons	.28	.56	.85	1.13	1.41	1.70
4 tons	.22	.44	.67	.89	1.11	1.34

Example: For safe load of 1,500 pounds per square foot sills of 3-inch thickness should have a length of $(1.54\times2)+1=4+$ feet. Those of 4-inch thickness should have a length of $(2.06\times2)+1=5+$feet. Both of which answers indicate safe designs. However, care must be taken not to design footings which are disproportionally long, since in the above case the use of 3-inch footings will result in the use of less wood and require less excavation. In the usual case footings should be at least 3 inches thick.

■ 55. INSPECTION AND REPAIR OF EXISTING MASONRY ABUTMENTS.—It has been stated that timber abutments will be used almost exclusively for new work in military operations; however, it will frequently happen that use can be made of existing masonry abutments by effecting suitable repairs. In such a case the abutments should be carefully examined for hidden mines. Examinations should also be made to determine the condition of the masonry and the thickness of the abutment. Often the quickest way to repair a masonry abutment will be to level it off and superpose a timber bridge seat.

■ 56. DEMOLITION CHARGES.—When tactical requirements warrant, demolition chambers should be provided in military bridges beneath the abutment bank seats. Such chambers should be placed at least 5 feet below the bank seats but not below flood level. If this is not possible with a chamber of 10 cubic feet normal capacity, two chambers should be placed, each with a capacity of 6 to 8 cubic feet. Unless a vertical shaft can be sunk quickly and easily from the roadway, the chamber (or chambers) should be made by excavating diagonally downward from in front of the footings. Both the chamber and shaft should be lined with timber, and 10 feet of tamping should be provided. The whole system should be planned so that the opening to the chamber is accessible at all times and in no danger of being flooded.

■ 57. BRIDGE LOADS.—*a. General.*—An understanding of stresses and their application is essential as an approach to the design of any frame structure. In the case of a bridge, certain stresses are induced by the live traffic loads for which it is designed, while others result from the dead weight of the structure itself. The distinction between live and dead loads is important, because the former may produce impact stresses as discussed in paragraph 51*b*; also, live loads may be either uniformly distributed along the length or the span or concentrated at one or more places. A given load concentrated and applied at the center of a span will produce twice the bending stress that would be developed by the same load uniformly distributed along the span.

b. Permissible military loads.—(1) The following limitations on gross weights of military vehicles are extracted from AR 850–15:

(*a*) The gross weight of a vehicle is defined as the chassis weight, plus the weight of the cab and the entire body, fully equipped and serviced for operation, plus the maximum allowable payload over good roads, and the weight of all operating personnel.

(*b*) The gross weight of any vehicle or combination of vehicles designed to accompany the military forces in the field and for movement by highway, or the gross weight carried by any group of two or more axles of such vehicles or combination of vehicles, will not exceed that given by the formula—

$$W = C(L+40)$$

where W=the gross weight of a vehicle or combination of vehicles or the gross weight carried by any group of two or more axles.

C=a coefficient which is prescribed below for different classes of vehicles.

L=the distance in feet between the centers of the first and last axles of the vehicle or combination of vehicles or between the centers of the first and last axles of any group of two or more axles.

(*c*) In applying the gross weight formula to a track-laying vehicle or to a combination in which there is a track-laying vehicle, the gross weight on the tracks will be considered as two axle loads, each equal to half the gross weight, applied either at the ends of the ground contact length of the tracks or at points halfway between the ends of the ground contact length and the center of the ground contact length, for the purpose of determining the length L, the greater gross weight being allowed in any case.

(*d*) In applying the gross-weight formula the following values of C will be used:

Type of vehicle	*Value of C.*
1. Vehicles designed to accompany an infantry or cavalry division or cavalry mechanized unit in the field, when the distance between the first and last axles of the group of axles considered is—	
18 feet or less	*325
Greater than 18 feet	*375
2. Vehicles designed to accompany an army in the field and for movement by highway, when the distance between the first and last axles of the group of axles considered is—	
18 feet or less	600
Greater than 18 feet	700

*This factor is for limiting loads for the present 7½-ton ponton bridge (model of 1926). It necessarily will be changed when tests have been conducted with the Standard Portable Highway Bridge (H–10), recently standardized; the contemplated 10-ton ponton bridge will also necessitate a like change in this factor.

(2) Limitations on axle, wheel, and track loads are as follows:

(*a*) The wheels of all vehicles except those operated at not to exceed 10 miles per hour will be equipped with pneumatic tires.

(*b*) No wheel equipped with a low pressure pneumatic tire will carry a load in excess of 9,000 pounds, nor will the total load carried by any axle having wheels equipped with such tires exceed 18,000 pounds. No wheel equipped with high pressure pneumatic, solid, or cushion tires will carry a load in excess of 8,000 pounds, nor will the total load carried by vehicle per lineal foot of ground contact will not exceed 5,000 pounds. An axle load will be the total load on all wheels whose centers are included between two parallel transverse planes 40 inches apart.

(*c*) Track-laying vehicles will have tracks of such length and width that at zero submergence the gross weight of the vehicle per lineal foot of ground contact will not exceed 5,000 pounds and the ground contact pressure will not exceed 15 pounds per square inch.

(*d*) No wheel equipped with pneumatic, solid, or cushion tires will carry a load in excess of 600 pounds for each inch of tire width. The width of pneumatic tires will be taken as the manufacturers' rating. The width of solid rubber and cushion tires will be measured at the flange of the rim.

c. Note on application of rules.—It should be noted that the above rules are published primarily as a guide to the designers of military vehicles for the Army. They are not to be used indiscriminately in the design of military bridges in the field, for the bridge provided will have to carry the actual loads with the unit concerned.

d. Design loads.—A suitable basis for the design of military bridges is to be found in the typical loadings of the American Association of State Highway Officials, and the corresponding classifications of bridges used by most State Highway Departments given below. Military loadings to be expected under AR 850–15 correspond to the type loadings and classifications sufficiently well, and hence, by using these, our military bridge designs will correspond with those in use on our modern highways. The following typical loadings (see fig. 29) have been approved:

	Class of loading	*Class of bridge*
For division bridges	H–10	*B*
For corps and army bridges up to 30 feet in span	H–15	*A*
For corps and army bridges over 30 feet in span	H–20	*AA*

■ 58. OTHER DESIGN CRITERIA.—*a. Width of roadway.*—Economy of materials requires that the width of roadway be no greater than that required to pass the loads. Infantry soldiers in single file require a walkway with a minimum width of 18 inches. Machine-gun carts and 37-mm gun carts

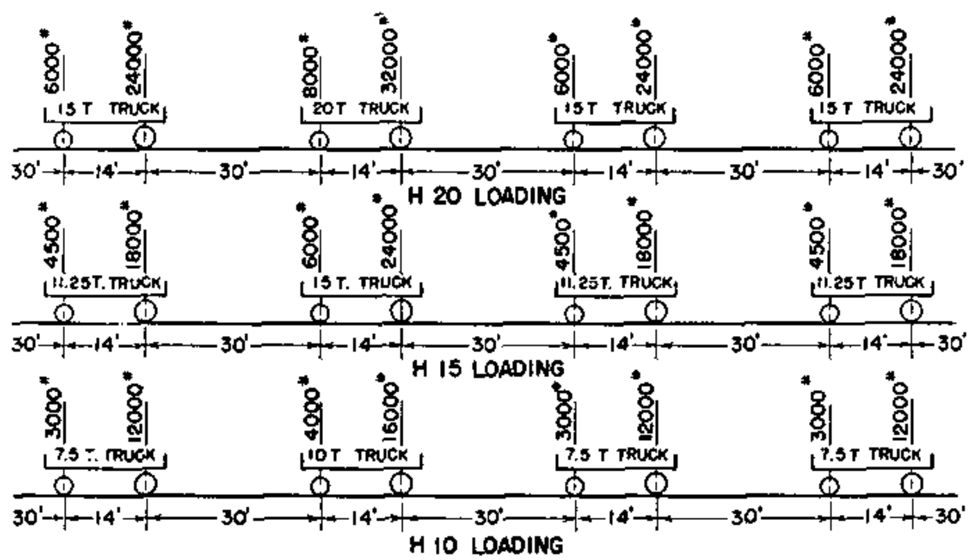


FIGURE 29.—Design loadings of the American Association of State Highway Officials.

require a minimum width of 4½ feet. These figures may be used in the design of very light assault bridges. For all other bridges the standards adopted are 10 feet clear width between curbs for a single roadway, and 18 feet clear width for a double roadway. Two one-way bridges will almost always be built, one after the other, in urgent situations rather than building a two-way bridge initially. For this reason the center line of a one-track bridge should not be placed on the center line of the roadway but should be placed on one side. Preferably, the first one-track bridge should be on the right-hand side when facing toward the enemy, so as to facilitate the forward movement of traffic toward the front.

b. Headroom.—The headroom for military bridges should

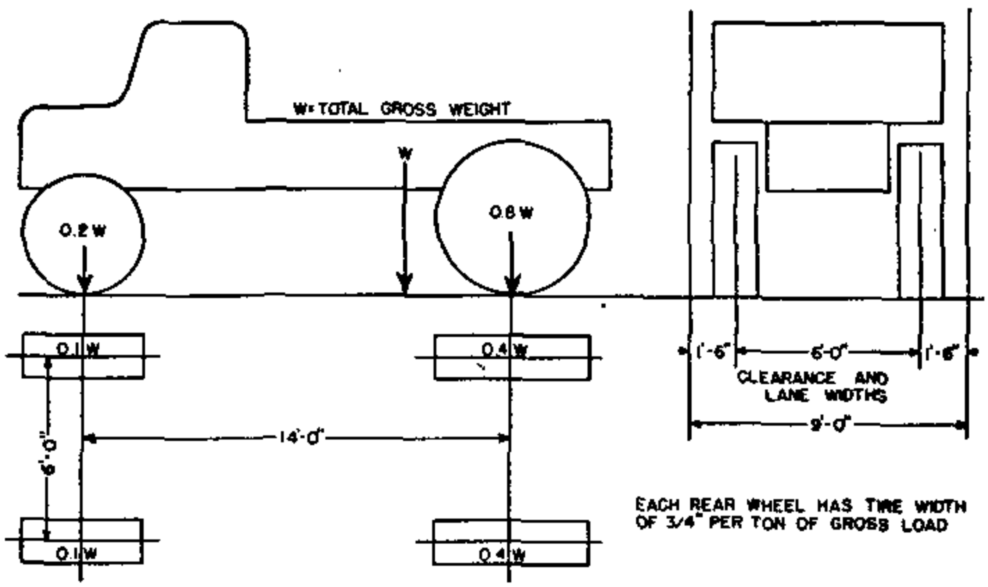


FIGURE 30.—Distribution of wheel loads for design.

be not less than 14 feet in order to permit the passage of general traffic, including trucks. This headroom is in excess of that required for military vehicles (11 ft.), but is the standard of the United States Bureau of Public Roads and should be furnished if practicable so that commercial trucks may pass if they are required to do so.

c. Clearance for navigation.—The clearance beneath the bridge depends upon the kind of river transportation which is permitted to use the stream under the existing military situation. It must be remembered that water transportation may have important military uses. Provision is made in the construction of floating bridges for making a draw of the required width to permit river traffic to pass.

d. Camber.—In order to allow for settlement in the foundations of bridges, and to check progress onto a bridge as well as to facilitate departure from it, it is advisable to make the center of a bridge higher than the ends. The rise should be 1 on 30 for about 30 feet from each end of the bridge when the approaches are at the same level. This rise is called *camber*.

e. Curbs and handrails.—Bridges should always be provided with curbs on both sides, and with handrails when possible. The handrail should be 3 feet above the roadway and outside of the curbs.

■ 59. STRESSES.—*a. General.*—Application of loads to a beam sets up internal stresses tending to balance the applied loads and transmit them to the supports. Table XV gives the allowable unit stresses for common structural woods, and table XVI those for steel. In military bridges, for simplicity, spans are considered as simple beams freely supported at the ends. The reactions at the supports are caused by the loads on the bridge, each of which is transmitted to the supports in inverse proportion to the distance of the load from each support.

b. Bending.—The bending effect of the applied loads is balanced by the resisting moment of the fiber stresses in the beam section. The bending moment at any section may be determined by taking the force of either reaction at the supports multiplied by the distance from that reaction to the section under consideration, and subtracting therefrom the product of all concentrated or distributed loads applied to the beam between that reaction and the section multiplied by the distances from these loads to the section. (See par. 77*d*.) The maximum allowable resisting moment within a given beam may be computed from the product of the maximum allowable fiber stress for the material, multiplied by the section modulus which is a measure of capacity of the cross-section to resist bending. Where M is the external bending moment impressed upon the beam by the loads, f the allowable extreme fiber stress for the material, and S the section modulus, their relationship is expressed by the formula $M=fS$. The section modulus depends solely on the shape and size of the cross section. For all rectangular beams, such as timber stringers, $S=\frac{bd^2}{6}$ where b and d are the breadth and depth of the section. For a round log $S=\frac{d^3}{10}$ where d is the diameter. S for I-beams and other structural steel beams may be found in tables in handbooks. S for minimum-web I-beams is given in table XVII. The stress f is ordinarily expressed in pounds per square inch, and b and d in inches, giving M in inch-pounds.

c. Shear.—The tendency of a load to shear the beam is balanced by the internal resistance to shear. The vertical shear at any section is the value of either reaction less the sum of the concentrated and distributed loads between that reaction and the section under consideration. The maximum vertical shear is developed at the supports, and occurs just as the maximum load is moving off the beam, that is, when the reaction reaches its maximum. Theoretically, the maximum horizontal shear should occur at the same point, but numerous tests conducted recently by the United States Forests Products Laboratory fail to substantiate this theory. (This is because a stringer acts as two beams in the case of horizontal shear near the supports.) These tests prove that the maximum horizontal shear actually occurs when the load is at a distance from the support of three times the beam depth, or at the center when the span is six times the depth or less. In wooden stringers horizontal shear rather than vertical shear is tested because it is usually greater, while the allowable fiber stresses for horizontal shear or splitting are always much less. The maximum unit horizontal shear in a beam can be found by placing loads as mentioned above, determining the reaction at the support, dividing by the cross section, and multiplying by $\frac{3}{2}$; or $S_h=\frac{3}{2}\left(\frac{R}{bd}\right)$. This stress occurs on a horizontal plane through the middle of a rectangular beam.

d. Bearing.—The total loads on the beam, including dead weight of the superstructure, are transmitted to the supports through the area of contact between the two. The maximum crushing tendency in a beam is developed when the maximum load is over a support; its intensity may be determined by dividing the maximum reaction by the area of contact. Safe unit stresses across the grain are included in table XV.

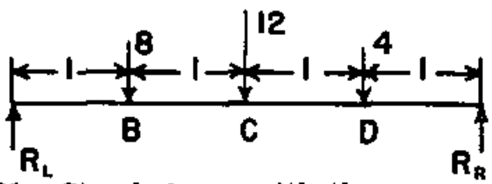


FIGURE 31.—Simple beam with three unequal loads.

e. Example.—Assume a simple beam with three unequal loads, as shown in figure 31. End reactions are determined by multiplying each applied load by its proportional distance from the support opposite to that considered, namely:

$$R_L = 0.75 \times 8 + 0.5 \times 12 + 0.25 \times 4 = 13$$
$$R_R = 0.75 \times 4 + 0.5 \times 12 + 0.25 \times 8 = 11$$

Check:

$$R_L + R_R = W_B + W_C + W_D$$
$$11 + 13 = 8 + 12 + 4$$

The external bending moment at C equals:

$$R_L \times 2 - W_B \times 1 = 26 - 8 = 18$$

This may also be found by taking forces from the right end:

$$R_R \times 2 - W_D \times 1 = 22 - 4 = 18$$

The vertical shear in section *CD* equals:

$$R_L - W_B - W_C = 13 - 8 - 12 = -7$$

which may be found also as follows:

$$R_R - W_D = 11 - 4 = 7$$

The units in which the forces and distances are expressed (pounds or tons, feet or inches) do not affect the numerical values of the answers as given; if pounds and inches, the moments and shears will be in inch-pounds and pounds, respectively; if tons and feet, the values in foot-tons and tons will be the same.

■ 60. CRITERION FOR MAXIMUM BENDING.—*a. General.*—For a moving load applied through two points, the maximum bending moment occurs when the distance from the center of gravity of the load to the point of maximum bending (the point of heaviest application) is bisected by the center of the span. This distance (r) of the center of gravity of the vehicle from the heavier load or axle (W_R) is found by multiplying the lighter load W_F by the distance between the axles (l) and dividing by the sum of the loads on both axles, which is the weight of the vehicle (W), or $r = W_F \times \frac{l}{W}$ (see fig. 32*a*). As stated above, the maximum bending moment occurs under W_R when the center of the span bisects r (i. e., is equidistant from W_R and W). There are limitations to the application of this rule, depending upon the relation between the parts of the total load and upon the relation between the span of the stringers and the distance between loads. Some common examples are shown in the four special cases below. Some military loads, as, for example, the four-wheel-drive truck, tanks, etc., have a ratio of 1:1 for front and rear axle loads. Other common ratios between front and rear axle loads are 1:2, 1:3, and 1:4. The special cases for these loadings are given below.

b. Special case I—two equal axle loads.—In this case the general criterion does not hold when the distance between axles exceeds 0.586 multiplied by the length of the span; the maximum bending moment then occurs when one of the loads is at the center of the span. (See fig. 32*b*.)

c. Special case II—two axle loads in the proportions of 1 to 2.—In this case the criterion does not hold when the distance between axles exceeds 0.551 multiplied by the length of the span; the maximum bending moment then occurs when the heavier load is at the center of the span.

d. Special case III—two axle loads in the proportion of 1 to 3.—In this case the criterion does not hold when the distance between axles exceeds 0.535 multiplied by the length of the span; the maximum bending moment then occurs when the heavier load is at the center of the span.

e. Special case IV—two axle loads in the proportion of 1 to 4.—In this case the criterion does not hold when the distance between axles exceeds 0.527 multiplied by the length of the span; the maximum bending moment then occurs when the heavier load is at the center of the span.

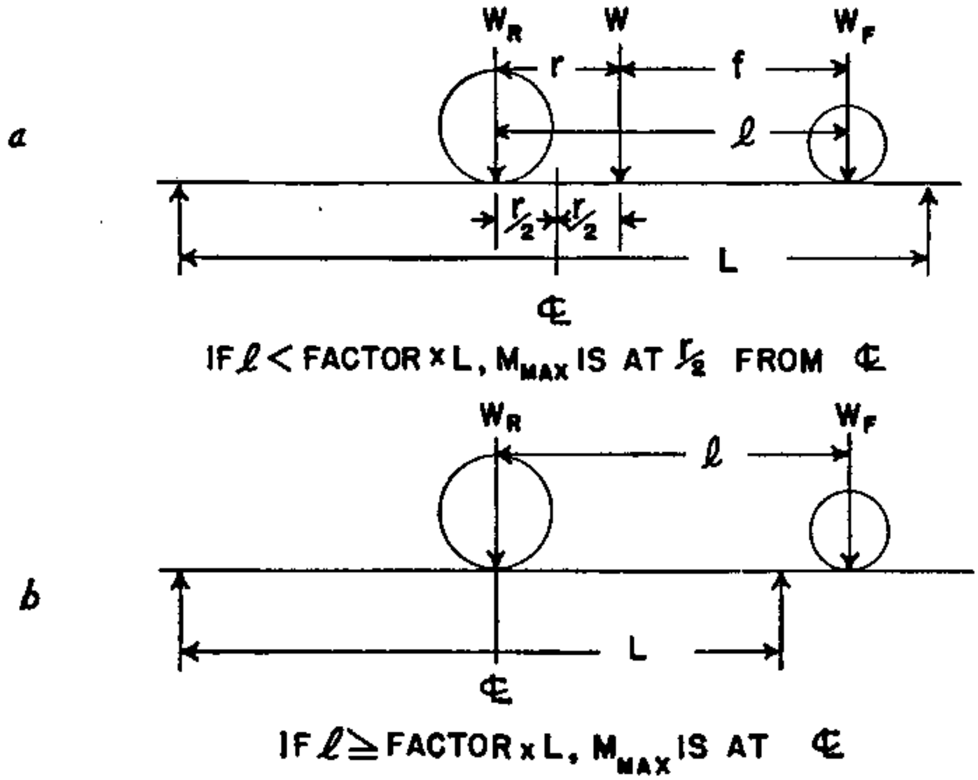


FIGURE 32.—Positions of heavier axle load on bridge to produce maximum bending.

■ 61. STRINGER BRIDGES.—*a. General.*—The simple stringer bridge is a single span bridge in which the longitudinal members (stringers) bearing the floor system rest directly on the bank seats. It is the simplest type of bridge to construct, and since the principles involved in its design and construction apply equally to trestle, pile, and similar bridges, the discussion applies with equal force to the latter types. Military bridges built in the field will, in general, be one or more stringer spans freely supported at the ends. For convenience and simplicity the stringers in any span are usually all of the same size.

b. Arrangement of stringers.—Figure 33 shows a typical placement of stringers in a one-track military bridge. The arrangement is such, it should be noted, as to give maximum direct support to wheel loads. When steel beams are used, nailing strips should be fastened to their upper flanges by lag screws or by small strips of strap iron bent over the flange as shown in figure 34.

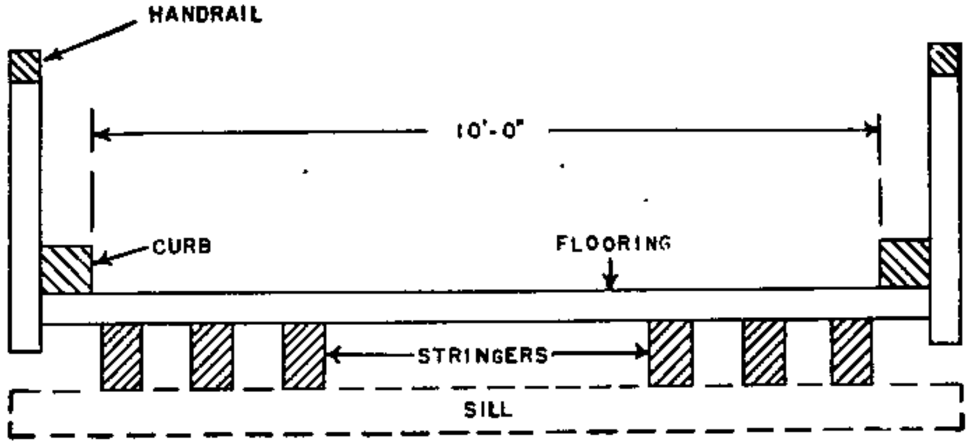


FIGURE 33.—Transverse cross section of typical stringer bridge.

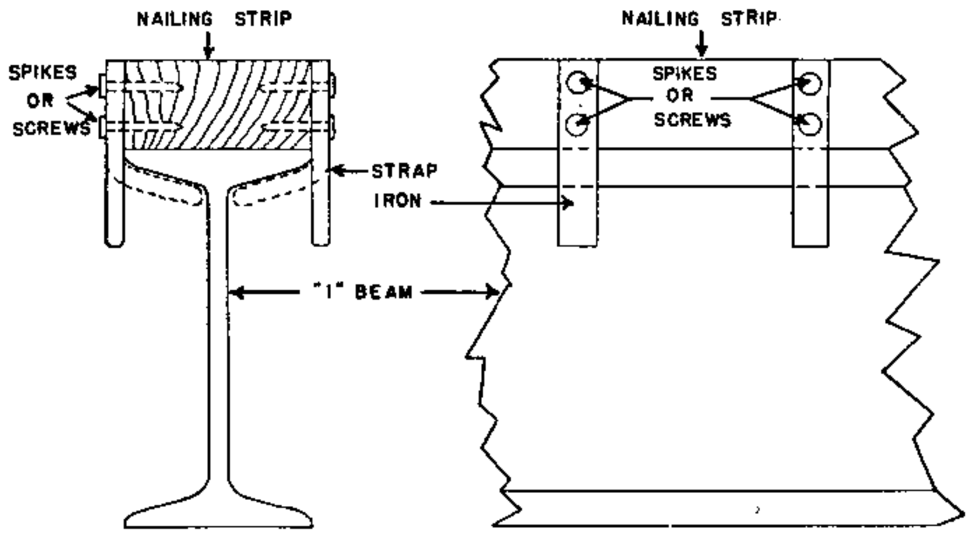


FIGURE 34.—Method of fastening nailing strip to I-beam.

■ 62. SAFE WORKING STRESSES.—*a. Wood.*—It is anticipated that the lower grades of structural timber will be stocked in engineer depots for issuance in war. Principal stockage will be of select, merchantable Douglas fir and No. 1, structural grade, yellow pine. The values of stresses for these and other grades and varieties of woods for a safety factor of 3 are given in table XV.

TABLE XV.—*Working stresses of common timber*

Variety and grade of lumber	Extreme fiber bending	Horizontal shear	Compression perpendicular to grain	Compression parallel to grain	Modulus of elasticity
Douglas fir					1,600,000
Dense select structural	2,400	145	500	1,700	
Select structural	2,100	125	450	1,600	
Select merchantable	1,600	125	425	1,300	
Yellow pine, longleaf, or dense shortleaf					1,600,000
Select structural	2,600	165	500	1,900	
Structural square edge and sound	2,100	165	500	1,700	
No. 1 structural*	1,600	165	500	1,600	
Redwood					1,200,000
Prime structural	2,000	105	350	1,600	
Select structural	1,700	90	350	1,450	
Heart structural	1,500	70	350	1,300	
Southern cypress					1,200,000
Select structural	1,700	125	400	1,450	
Common structural	1,400	105	400	1,150	
Eastern hemlock					1,100,000
Select structural	1,450	90	400	900	

*Basis of engineer board designs.

b. Steel.—For the design of steel military bridges, the usual commercial unit stresses given in pounds per square inch in table XVI may be increased by 25 percent, which gives a factor of safety of 1.75; this allows the basic unit stress in bending of 18,000 pounds per square inch to run as high as 22,500 for small values of $\frac{L}{b}$.

TABLE XVI.—*Design unit stresses for steel used in civil practice*

Type of stress	Amount of stress, pounds per square inch
Direct axial tension on net section	18,000
Direct axial compression, maximum for short columns	14,000
Compression in columns	$18,000-70\frac{L}{r}$*

For footnote see end of table.

TABLE XVI.—*Design unit stresses for steel used in civil practice*—Continued.

Type of stress	Amount of stress, pounds per square inch
Fiber stress in flexure, in tension, or in compression when the unsupported length (L) is not more than 15 times the breadth (b)	18,000
Compressive fiber stress in flexure for value $\frac{L}{b}$ between 15 and 40	$22,000-270\frac{L}{b}$
Fiber stress in pins	27,000
Bearing on plane faced or rolled surfaces	27,000
Shear in gross section of webs of girders and rolled shapes in which (d), the unsupported depth between flanges or the distance between stiffeners, if less, divided by (t), the thickness of web, does not exceed 43	12,000
Shear when $\frac{d}{t}$ exceeds 43	$15,000-70\frac{d}{t}$
Shear in power-driven rivets or in pins	13,500
Shear in hand-driven rivets or in rough bolts	10,000
Bearing upon power-driven rivets or in pins subjected to single shear on one side of the bearing in question	24,000
Bearing upon power-driven rivets or on pins when the bearing metal lies between two planes of shear of opposite character immediately adjacent	30,000
Bearing upon hand-driven rivets or on rough bolts subjected to single shear on one side of the bearing in question	16,000
Bearing upon hand-driven rivets or on rough bolts when the bearing metal lies between two planes of shear of opposite character immediately adjacent	20,000

NOTE.—For design all values in this table may be increased 25 percent.

*Compression stresses in columns, computed by the formulas for column design, may not exceed in any case the maximum for direct axial compression short columns. L=length of column; r=least radius of gyration.

■ 63. **DISTRIBUTION OF LOADS TO STRINGERS FOR DESIGN.**—The formula of the American Association of State Highway Officials' Specifications states that for design the fraction of a wheel load transmitted to each interior stringer is assumed to be the stringer spacing in feet divided by four, with the maximum spacing limited to 4 feet. This value, $\frac{S'}{4}$, has been adopted for use in the design of military bridges by applying it to all stringers and deducting from it one-half the excess of this value over that obtained by assuming that the load is distributed equally over all the stringers. Using symbols

N =total number of stringers
S'=stringer spacing in feet center to center

the proportion of the wheel load on any one stringer is given by

$$\frac{S'}{4}-\left(\frac{\frac{S'}{4}-\frac{2}{N}}{2}\right)=\frac{S'}{8}+\frac{1}{N}$$

Thus, for 6 stringers uniformly distributed over a one-track bridge of 10-foot width, $S'=\frac{10'}{5}=2$ feet. Hence, the proportion of a wheel load that must be carried by any stringer is from the formula: $\frac{2}{8}+\frac{1}{6}=.25+.16$, or nearly 42 percent.

If both axles are on the bridge, this proportion of both front and rear wheel loads are assumed to be carried by one stringer. For ordinary design or investigation of small bridges in the field under war conditions, distribution as determined by good judgment or inspection will be sufficiently adequate for most purposes. For instance, in the case of a simple one-track stringer bridge, with an even number of stringers, it is considered that stringers can be placed to allow a stringer efficiency of 90 percent to be used in design. However, for large bridges or special or important designs, the above formula should be used. In addition, of course, the condition that the sum of the fractional capacities of all the stringers is not less than the total of all live and dead loads on the span should apply, or the sum of all percentages at least equal unity. This common sense condition means that all stringers, regardless of assumed distributions, must, when taken together, have at least enough load capacity to carry the imposed loads on the bridge.

■ 64. DESIGN OF STRINGERS.—*a. General.*—The first step is to determine the total maximum bending moment produced by the combined live and dead loads (plus impact if considered), and then use enough stringers of suitable size to withstand it. In hasty design of short span bridges, it is usually sufficient to add an extra stringer to take care of the dead load, if this has not already been taken into account. For long spans using stringers of small size, it may be necessary to add stringers for the dead load up to 25 percent of the number needed for the live load.

b. Determination of bending moment.—The maximum bending moment may be determined by means of the following formulas, in which W=total load in pounds; L, the span in inches; and M, the moment in inch-pounds at the center of a simple beam:

$M=\frac{WL}{4}$ (for concentrated center load, W)

$M=\frac{WL}{8}$ (for a total load, W, uniformly distributed over a length of L feet)

The maximum moment caused by a moving, uniform load, partially distributed, is:

$M=\frac{W(4a+b)}{8}$, where

W=the total load

L=length of span in inches

b=length of load in inches, and

$a=\frac{L-b}{2}$ in inches

The resisting moment must be equal to or greater than the bending moment to which the stringer is subjected. This can be determined by the following formulas:

$M=fS$ (for all beams)

$M=\frac{fbd^2}{6}$ (for rectangular wooden beams)

$M=\frac{fd^3}{10}$ (for round timbers)

where f=maximum working fiber stress for the material

b=breadth of wooden beam in inches

d=depth of wooden beam in inches (diameter round timbers)

S=section modulus of steel beams, from handbook tables in inches cubed (in.^{3})

M=resisting moment in inch-pounds

The resisting moment of all the stringers (corrected for stringer efficiency or wheel-load distribution) must be equal to or greater than the total maximum (external) bending moment produced by the loads on the bridge. The maximum external moment is made equal to the number of stringers times the corrected internal resisting moment of each stringer. From this the required number of stringers may be found; or given a predetermined number of stringers, one dimension or the section modulus may be found, thus determining the size.

c. Stringer diagrams.—(1) In practice, stringers are commonly selected by means of specially prepared diagrams and tables. Figures 35 and 36 have been prepared especially for the use of the military engineer in the field for a one-track bridge. They are also useful for checking the capacity of existing bridges by reversing the normal process. Tables XVII, XVIII, and XIX permit the selection of stringers by inspection, but do not include dead load, stringer efficiency, or impact stresses. In computing these diagrams a maximum fibre-bending stress of 18,000 pounds per square inch for steel, 1,600 pounds per square inch for timbers, and 1,000 pounds per square inch for logs was used. The I-beams given are the lightest weight standard beams. Only the critical H-loadings were selected, inasmuch as a bridge designed to carry these loads will carry all other lighter loads. For example, a bridge designed for H–10 loads will carry all loads normally with the division.

(2) The diagram for rectangular timber stringers (fig. 35) is for live loads only, with loads assumed equally distributed among all stringers and no allowance made for impact. For more exact determinations, the dead-load moment and stringer efficiency or distribution should be taken into account and correction made for the actual allowable safe stresses. Use of the diagram is illustrated by the following problem:

(*a*) How many 6- by 10-inch stringers of material with unit-safe stress of 1,600 pounds per square inch are required to carry the H–15 loading on a 10½-foot span? (Disregard impact and stringer efficiency.)

(*b*) *Solution.*—The broken lines *X–X′* show the method of solution. Enter the loading diagram where the H–15 loading line crosses the 10½-foot span, go right horizontally to the index line on the stringer diagram, then vertically upward to the line marked 10 inches deep. Again go right horizontally to *X′*, where the total width of stringers required is nearly 28 inches. Therefore the number of stringers required is $\frac{28}{6}=4.67$, or 5 stringers. If one stringer is added for dead load, this will check with the solution obtained by analytical methods.

(*c*) *Illustrative inspection problem.*—What type of H-loading will a 15-foot-span bridge carry which has 75 inches total width of 8-inch-deep stringers of 1,600 pounds per square inch, safe stress, so properly placed as to share the loads equally? (Disregard impact, dead load, and stringer efficiency.)

(*d*) *Solution.*—The broken lines *Y–Y′* show the method of solution. From the point where the total width of stringers is 75 inches, go left horizontally to the line marked 8 inches deep, then go vertically downward to the index line, and thence horizontally to the left to the vertical line for 15-foot stringer spans. As this point is between the H–15 and H–20 loading lines, it is seen that the stringers will carry the H–15 loading safely but will not carry the H–20 loading.

(3) The diagram for I-beams and round logs stringers (fig. 36) is used in manner similar to that of figure 35, with no impact allowance and all stringers assumed to carry equal portions of the load. For more exact determinations, the dead-load moment, impact, and stringer efficiency should also be considered. The following problem is for illustrative purposes:

(*a*) How many minimum weight 6-inch I-beams are needed to carry the H–10 loading on a span of 15 feet? How many round green logs of solid timber, 12 inches in diameter, are required under these same conditions?

(*b*) *Solution.*—The dotted line *X–X'* shows the method of solution. From the intersection of the H–10 loading line with the 15-foot span line, go to the left horizontally to *X* and under the 6-inch–12.5-pound column; it is seen that six I-beams of this type are required. From the same intersection as above, go to the right horizontally until the 12-inch diameter line is reached at *X'*. This point is between the curves for 3 and 4 round logs required, indicating that 4 logs should be used.

(*c*) *Illustrative inspection problem.*—How long a span can the H–10 loading cross over safely if six 7-inch, 15.3-pound, I-beams are used as stringers? What loading will six logs of 12-inch diameter carry safely over a span of 14 feet?

(*d*) *Solution.*—The broken lines *Y* and *Y'* show the methods of solution. Under the column for 7-inch I-beams from the line between 6 and 7 beams, go to the right horizontally to meet the H–10 loading line at *Y*. This shows the safe stringer span is 24 feet. From the intersection of the curve for 6 round logs with the 12-inch diameter line, go left horizontally to meet the 14-foot span line at *Y'*. As this point is above the H–15 loading line, the H–15 type of loading is safe.

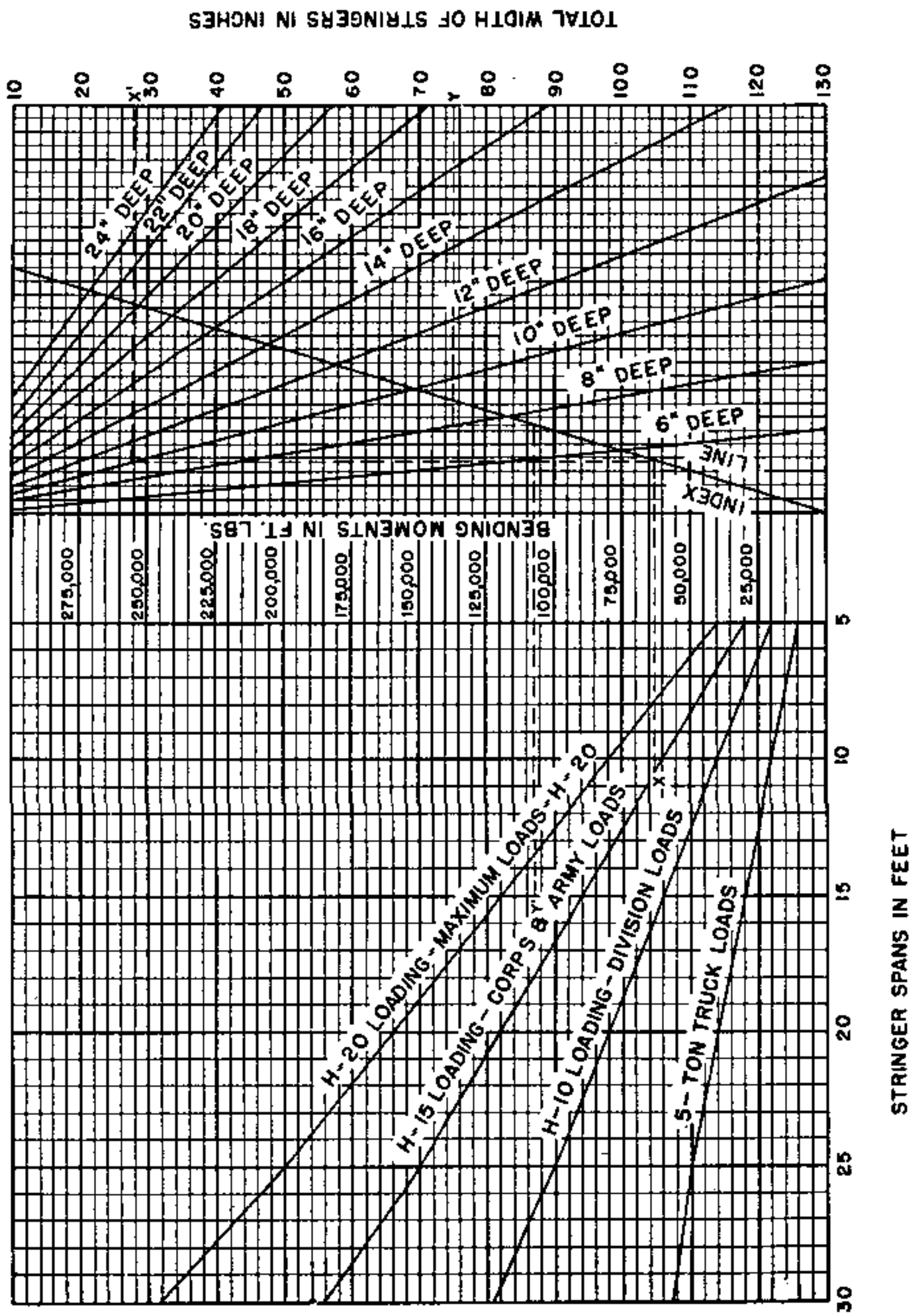


FIGURE 35.—Diagram for rectangular timber stringers.

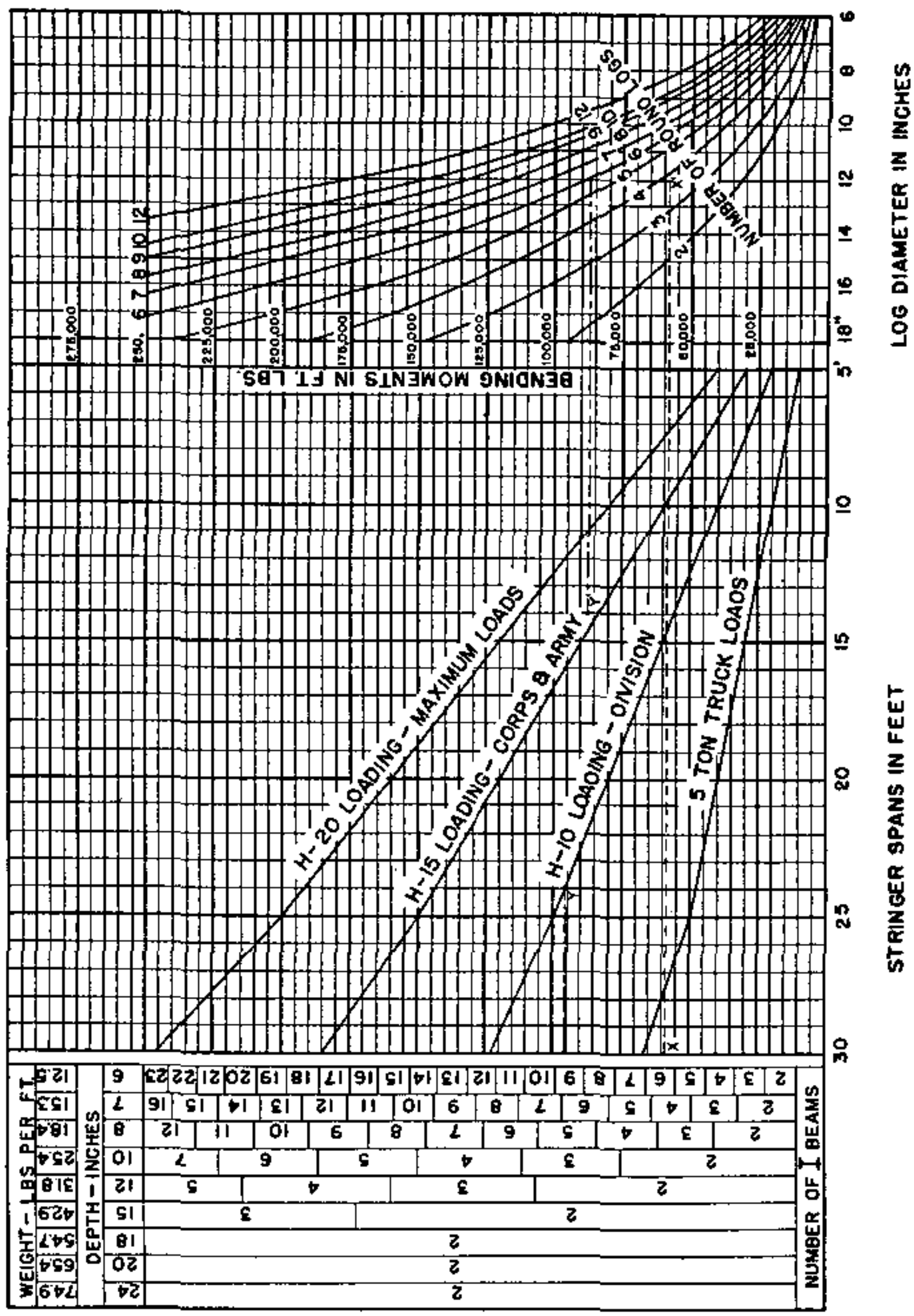


FIGURE 36.—Diagram for I-beams and round log stringers.

TABLE XVII.—*Safe loads for single I-beams*

American standard steel I-beams, minimum thickness (simple end supports) safe concentrated load in pounds. (For uniformly distribute loads use double these values.) Based on a stress of 18,000 pounds per square inch, take proportionate safe loads for smaller or greater unit stresses. For heavier beams of same depth the percentage increase in safe load is approximately one-half the percentage increase in weight of beam. The last loads given should not be used on spans below the black line as they will produce excessive deflections.

Span in feet	3 inches 5.7 pounds	4 inches 7.7 pounds	5 inches 10.0 pounds	6 inches 12.5 pounds	7 inches 15.3 pounds	8 inches 18.4 pounds	10 inches 25.4 pounds	12 inches 31.8 pounds	15 inches 42.9 pounds	18 inches 54.7 pounds	20 inches 65.4 pounds	24 inches 79.9 pounds
5	2,000	3,600	5,800	8,700	12,400	17,050	29,300	43,150				
6	1,650	3,000	4,850	7,250	10,350	14,200	24,400	35,950				
7	1,400	2,550	4,150	6,200	8,850	12,200	20,950	30,850				
8		2,250	3,650	5,450	7,750	10,650	18,300	27,000	44,200			
9			3,250	4,850	6,900	9,500	16,300	24,000	39,250			
10			2,900	4,350	6,200	8,550	14,650	21,600	35,350	53,050	70,150	104,350
12				3,650	5,200	7,100	12,200	18,000	29,450	44,200	58,450	86,850
14					4,450	6,100	10,450	15,400	25,250	37,900	50,100	74,550
16						5,350	9,150	13,500	22,100	33,150	43,850	65,250
18							8,150	12,000	19,650	29,450	39,000	58,000
20								10,800	17,650	26,500	35,100	52,200
25									14,150	21,200	28,050	41,750
30										17,700	23,400	34,800
35										15,150	20,050	29,800
Section modulus *S*-In	1.7	3.0	4.8	7.3	10.4	14.2	24.4	36.0	58.9	88.4	116.9	173.9

TABLE XVIII.—*Safe loads in pounds for rectangular wooden beams 1 inch wide*

Span in feet	Depth of beam in inches										
	4	6	8	10	12	14	16	18	20	22	24
2	710	1,125	1,500	------	------	------	------	------	------	------	------
4	356	800	1,425	1,875	2,250	------	------	------	------	------	------
6	237	533	950	1,480	2,135	2,625	3,000	------	------	------	------
8	177	400	710	1,110	1,600	2,175	2,845	3,375	3,750	4,125	------
10	143	320	570	888	1,280	1,745	2,279	2,880	3,550	4,300	4,700
12	118	267	475	740	1,066	1,454	1,896	2,400	2,960	3,580	4,260
14	------	228	406	635	914	1,245	1,626	2,055	2,580	3,072	3,655
16	------	200	356	556	800	1,090	1,424	1,800	2,225	2,690	3,200
18	------	------	316	494	710	968	1,264	1,600	1,975	2,390	2,848
20	------	------	284	444	640	871	1,137	1,440	1,778	2,150	2,560
22	------	------	------	404	581	792	1,035	1,308	1,617	1,956	2,328
24	------	------	------	371	533	727	948	1,200	1,481	1,794	2,132

NOTES

1. Above figures are safe loads which may be carried by a stringer, 1 inch wide, on simple end supports, assuming:

Extreme fibre stress=1,600 pounds per square inch, and
Safe horizontal shearing stress=150 pounds per square inch.

2. For stringer 6 inches wide, multiply loads in table by 6.
3. Impact, dead load, and stringer efficiency not considered.
4. Figures above the black line are determined by computations of horizontal shear, which controls in the case of short spans.
5. Figures above the black line apply to either a concentrated or a uniform load. Below this line loads may be doubled in the latter case.
6. Computations are based on net sections, hence if timbers are dressed to lesser dimensions, proportional corrections must be applied.

TABLE XIX.—*Safe load for round timber stringers*

Span in feet	Diameter of beam in inches											
	2	3	4	5	6	7	8	10	12	14	16	18
2	131	441	1,048	------	------	------	------	------	------	------	------	------
3	88	294	698	1,366	------	------	------	------	------	------	------	------
4	65	221	524	1,022	1,768	2,808	------	------	------	------	------	------
5	52	176	419	820	1,412	2,245	3,350	6,544	11,310	------	------	------
6	----	147	349	684	1,178	1,871	2,790	5,462	9,425	14,961	22,340	31,808
8	----	110	262	511	884	1,404	2,092	4,088	7,069	11,225	16,754	23,856
10	----	89	209	410	706	1,123	1,675	3,272	5,655	8,980	13,404	19,086
12	----	74	175	342	589	935	1,395	2,732	4,713	7,482	11,170	15,904
14	----	----	150	292	506	802	1,198	2,340	4,065	6,415	9,574	13,632
16	----	----	131	256	442	702	1,046	2,044	3,534	5,613	8,377	11,928
18	----	----	116	228	393	625	931	1,818	3,142	4,989	7,447	10,603
20	----	----	105	205	353	562	838	1,636	2,827	4,490	6,702	9,543
22	----	----	96	186	322	511	763	1,489	2,570	4,082	6,093	8,675
24	----	----	------	171	295	469	698	1,365	2,356	3,742	5,585	7,952

NOTE.—Safe concentrated load in pounds (simple end supports). Based on 1,000 pounds per square inch in extreme fibers due to actual weight of load. In general, round timber stringers need not be tested for horizontal shear.

■ 65. BRIDGE SUPPORTS, GENERAL.—Trestle and pile bents are simple and efficient bridge supports. Trestles are particularly advantageous in military operations, as they are simple in construction details, easy of erection, and economical in use of timber. They can be used where the bottom is sufficiently firm to support the load, except when the depth or scouring action of the water in the stream crossed is too great. When the bottom is soft and muddy, or sandy and shifting, trestles cannot be used unless measures are taken to increase the bearing, or elaborate protective means are adopted. In such cases pile bents or cribs should usually be employed. Due to their ease of construction, trestle bridges should be used ordinarily, and piling or cribs only when necessary or more desirable.

■ 66. DESIGN OF TRESTLE BENTS.—*a. Posts.*—Posts must be designed as columns, especially where they are long in proportion to their least cross-section dimension. Loads on posts are determined by placing the loading diagram used to produce the greatest reaction in these members. For military bridges the value of $\frac{L}{d}$ should not exceed 40. The formulas for stresses specified for use in the design of columns for military bridges are those of modern civil engineering practice, with modification, which reduces the factor of safety from 3 to 2.5, as follows:

(1) For short columns with $\frac{L}{d}$ ratios of 11 or less, the allowable working stresses (p) are the same as those given in table XV for compression parallel to the grain. L is the unsupported length of column and d is the least dimension of the column; both must be expressed in the same units of measure.

(2) Columns of intermediate length are classified as having $\frac{L}{d}$ ratios between 11 and K. The value of $K=0.64\times\sqrt{\frac{E}{s}}$, where E=modulus of elasticity and s=the working stress adopted for compression parallel to the grain for short columns, both taken from table XV. When not otherwise given, E=1,600,000 and s=1,300, both expressed in pounds per square inch, for which values K=22.5. The allowable unit working stress is obtained from the formula:

$$p=s\left(1-\frac{1}{3}\left(\frac{L}{Kd}\right)^4\right).$$

(3) Long columns have $\frac{L}{d}$ ratios equal to K or greater. The following formula gives the allowable unit stress:

$$p=1.2\times0.274\times\frac{E}{\left(\frac{L}{d}\right)^2}$$

The total allowable load on the column (P) is given by the formula $P=pA$, where p is the allowable stress as determined above and A is the cross-sectional area of the column expressed in corresponding units.

(4) For round columns the allowable stresses should be determined for an area of cross section equivalent to that of a square column of the same area. The square root of the area of cross section of the round column will give the side of the equivalent square which should be used as the

value of d in determining the allowable unit stress, p. The ratio of the diameter of a circular cross section to the side of the square with an equivalent area is approximately 79:70. The following table gives the value of the expression

$$\left(1-\frac{1}{3}\left(\frac{L}{Kd}\right)^4\right)$$

in the formula for the allowable stress for intermediate columns in percent. If $\frac{L}{d}=16$ and $K=20$, the value is 0.86.

TABLE XX.—*Values of the expression* $\left(1-\frac{1}{3}\left(\frac{L}{Kd}\right)^4\right)$

Values of K	$\frac{L}{d}$ ratio of length to least dimension in rectangular timbers												
	11	12	13	14	15	16	17	18	19	20	21	22	23
11	0.67	----	----	----	----	----	----	----	----	----	----	----	----
12	0.76	0.67	----	----	----	----	----	----	----	----	----	----	----
13	0.83	0.76	0.67	----	----	----	----	----	----	----	----	----	----
14	0.87	0.82	0.75	0.67	----	----	----	----	----	----	----	----	----
15	0.90	0.86	0.81	0.75	0.67	----	----	----	----	----	----	----	----
16	0.92	0.89	0.86	0.80	0.74	0.67	----	----	----	----	----	----	----
17	0.94	0.92	0.89	0.85	0.80	0.74	0.67	----	----	----	----	----	----
18	0.96	0.94	0.91	0.88	0.84	0.79	0.73	0.67	----	----	----	----	----
19	0.97	0.95	0.93	0.90	0.87	0.83	0.78	0.73	0.67	----	----	----	----
20	0.98	0.96	0.94	0.92	0.89	0.86	0.83	0.78	0.73	0.67	----	----	----
21	0.98	0.97	0.95	0.93	0.92	0.88	0.86	0.82	0.77	0.72	0.67	----	----
22	0.98	0.97	0.96	0.94	0.93	0.91	0.88	0.85	0.81	0.77	0.72	0.67	----
23	0.99	0.98	0.97	0.95	0.94	0.92	0.90	0.87	0.84	0.81	0.77	0.72	0.67

NOTE.—This table can also be used for timber columns not rectangular $\frac{L}{d}$ being equivalent to 0.289 $\frac{L}{r}$ where r is the least radius of gyration of the section.

b. *Caps and sills*.—Caps and sills, in general, should have a least dimension in width equal to the diameter of the posts and usually a greater dimension in depth. Within the limits of timber sizes usually available, and with customary stringer arrangement, investigation of caps for failure from bending stresses or shear is generally unnecessary. The same remark applies to investigation for failure of caps and sills due to crushing at the connections with the posts. Doubtful cases arising from heavy loads, light timbers, and unusual arrangement should be investigated for shear and crushing.

c. *Footings (mudsills).*—Trestle footings require an area of bearing sufficiently large to prevent their sinking into the soil. They should be designed in the manner described for bridge seats (par. 54).

■ 67. DESIGN OF PILE BENTS—*a. General.*—Pile bents are constructed in dimensions corresponding to trestle bents, the standard cap being used. When the height from the bottom is 8 feet or less, no bracing is required. For greater heights, horizontal bracing is fastened across the bent above water level, and sway bracing is placed as for trestle bents. Heights greater than the length of piles available may be built from combinations of pile and trestle bents. Longitudinal bracing corresponds to that for trestle bents. For greater stability the outside piles and sometimes others in a pile bent are driven at a slant, called "batter," with the top of the pile leaning toward the center of the bent. Piles are sawed off to the proper level by nailing a board levelly across the bent and sawing along the board.

b. Piles.—If the bearing value of a pile is derived from having its lower end resting on a hard stratum, the pile is designed as for a column. If its bearing value is derived from the surface friction all along its embedded length, the safe load is determined either by loaded test piles or by the following formulas, which may be applied to test-driven piles or to piles as they are driven.

For piles driven by drop hammer: $P=\frac{2wh}{s+1}$

For piles driven by steam hammer: $P=\frac{2wh}{(s+0.1)}$

P=safe load in pounds

w=weight of hammer in pounds

h=height of fall of hammer in feet

s=average penetration of the pile under several successive blows of the hammer, in inches

The safe load on piles driven by jetting is determined by test loads, or the above formula may be used if the piles are partially jetted down and driven the last 5 feet. This is usually an advantageous procedure. All piles should be driven to a least penetration of 8 feet; in the case of wooden piles there is no advantage to driving them to greater depths than 35 feet in sand or other homogeneous material. Table XXI below gives probable safe loads for various penetrations in various bottoms.

TABLE XXI.—*Bearing power of piles due to penetration in different soils (for piles of 1 foot mean diameter)*

Character of soil	Penetration	Probable safe load	Character of soil	Penetration	Probable safe load
	Feet	*Pounds*		*Feet*	*Pounds*
Soft mud	15	4,500	Compact sand	10	20,000
	30	10,000		12	24,000
Soft clay	10	7,000		15	28,000
Compact silt	15	10,000		20	36,000
	20	13,000		30	48,000
	30	20,000	Sand and gravel	8	20,000
Stiff clay	10	15,000		10	24,000
	15	23,000		12	28,000
	20	30,000		15	34,000
	30	45,000		20	43,000
Compact sand	8	16,000		30	60,000

For piles of other sizes, increases or decreases proportional to the diameters of the piles should be taken, based upon the values in the above table if the piles are larger or smaller than the size given. For large and important structures, safe pile loads for design should be determined if possible by test-loaded piles rather than by the above formulas or tables. This is particularly important because in many cases it will be found possible to use higher design loads.

■ 68. TIMBER PIERS.—*a. General.*—Timber piers may be of trestle, pile, or crib construction. The type of structure to be selected depends on the conditions of the crossing. Trestle piers are used where the water is shallow, the bottom fairly firm and even, and the scouring action small. Pile piers are used where the bottom of the stream is soft and uneven, the current swift, or the water deep. If the current is very swift, it may be necessary to protect the piers against scour by derrick stone or riprap. Crib piers may be adapted to many sites but require much timber and labor to erect.

b. Trestle piers.—For heavy girder or truss bridges a pier consisting of two trestles framed together gives a better support than a single bent. The two trestles give greater stability and stiffness and also facilitate the seating of the bridge span. In single trestles, corbels or bolsters would have to be provided to give sufficient bearing. Stiffness and stability require that the columns in a pier be at least 8 by 8 inches in cross section, although actual design may show smaller sizes sufficient. If possible, the trestle should be placed in firm, undisturbed ground and never upon a fill, if it can be avoided. Beds for the footings under water should be excavated evenly. Trestles must be placed symmetrically on the footings. Often the excavation for footings can be filled with tamped broken stone. Where there is considerable scour, a bulkhead or heavy riprap should be placed around the pier.

c. Pile piers.—Standard pile piers consist of two pile bents spaced 4 feet apart. The piles must be driven to a sufficient depth to have each safely support its proportionate share of the load.

d. Crib piers.—Crib piers consist of a frame of logs or beams filled with stones, rubble, or the like, so constructed that the part which stands in water forms a cage for the ballast. They are easily adapted to all sites and easy to erect, but require much timber. Timbers of the size used in corduroy roads are suitable for crib construction.

e. Ice conditions.—In open rivers where large quantities of ice are likely to be encountered, it may be difficult to maintain pile bent, trestle bent, or pier bridges at such a time. If these conditions are expected, special consideration should be given to possible means of protection and to providing temporary expedients, such as ponton crossings in case the bridge is destroyed.

■ 69. RAILS, CURBS, AND FLOORING.—A curbing should be provided on each side of the floor system. This necessitates flooring at least 11 feet in length for a bridge with a 10-foot roadway. If 12-foot flooring is available, it may be laid diagonally. Any thickness of flooring may be used, but for bridges designed for the heaviest traffic, two layers of 3-inch flooring are needed and more are desirable. For light vehicular bridges flooring of not less than 3-inch thickness should be used except in the case of special flooring such as chess. At least one spike per stringer, and preferably two, should be provided if materials and time permit. The curb is best made of 6-by-6-inch timber bolted to the outer edges of the flooring to prevent vehicles from going off the bridge, but 4-by-6's on edge may be used and even three 2-by-6's, spiked one on top of the other, will serve very well. The curb may be bolted, spiked, or lashed in place. The handrail and standard should be at least 2 by 4 inches in cross section and 4-by-4-inch posts are desirable. Figure 33 shows these various elements in a simple stringer bridge. Dry flooring should be laid with about ¼" between planks to allow for swelling when wet.

Section III

RECONNAISSANCES AND INVESTIGATIONS

■ 70. General.—Bridge reconnaissances may be of several kinds, depending upon the uses to which the desired information will be put. A simple means of classification is as follows:

a. Tactical reconnaissance.—To determine bridge data relative to prosecution of tactical operations.

b. Technical reconnaissance.

(1) Routine inspections for maintenance.

(2) Special reconnaissance for new construction, particularly of possible bridge sites.

(3) Inspections of existing structures as bases for investigations of their carrying capacities.

Information for any purpose in connection with bridge operations may be obtained from maps, aerial photographs, local inhabitants, special intelligence reports, prisoners, and personal reconnaissance. While all of these sources of information should be used, the personal reconnaissance is necessary in any case in order to verify the other information and obtain accurate data.

■ 71. Reconnaissance Party.—*a. Personnel.*—The reconnaissance party should always include an engineer officer. This is especially necessary when tactical commanders are reconnoitering in connection with river-crossing operations when, although tactical considerations may predominate, the advice of an engineer is necessary in order that technical considerations may not be overlooked. An engineer reconnaissance party should include, if possible, the commander of the troops who will do the construction. The party need not be large, often the leader with one or two assistants being sufficient.

b. Equipment.—The reconnaissance party should be equipped with transportation, prismatic compass and tape for measuring the width of the stream, hatchet for cutting and driving stakes, string and plummet for making soundings, and, if circumstances permit its use, a skiff or assault boat. A camera may be found useful for taking pictures to be incorporated in the reconnaissance report.

c. Report.—The report of the reconnaissance party should include a clear explanation of all data obtained, illustrated with one or more sketches, and should recommend the type of bridge to be built or the repairs to be made. It should include a bill of materials and list of tools together with an estimate of labor and time required for the construction and the transportation necessary; the condition and location of the routes approaching and leading from the bridge site should be covered in the report. A form for making the report of a bridge reconnaissance is shown in paragraph 73*b*(8).

■ 72. Tactical Reconnaissance.—Tactical considerations govern in the selection of a bridge site unless the encountered technical difficulties are such as to influence a final choice. Concealed preparations result in surprise both as to time and location. Speed is also essential. Hence covered areas, accessible by existing approach roads, should be sought in the immediate vicinity of a site. The type of bridge to be used depends upon technical considerations such as characteristics of the bridge site, available materials, and character of the loads to be transported. Tactical considerations, such as the necessity for the immediate passage of certain combat loads, may dictate the construction of a light structure, at least in the early stages of the operation, to be reinforced or replaced by a heavier structure as the operation progresses and as the need arises for the passage of the heaviest army loads.

■ 73. TECHNICAL RECONNAISSANCE.—*a. Routine inspections.*—All bridges in the area occupied by the field forces should be inspected periodically, the intervals dependent upon the types and importance of the bridges, their condition, and the density of traffic over them. At least one thorough inspection per month should be made by an officer having special knowledge of bridge construction. Purposes of these inspections are—

(1) To ascertain the amount of deterioration of the structure and to discover weakness or defects.

(2) To determine the safety of the structure under maximum conditions of load, or the limiting safe loads in its present condition.

(3) To decide upon repairs or changes in sign-posting necessitated by (1) or (2) above.

b. Reconnaissance for new construction.—(1) *Siting the bridge.*—The final decision in siting a new bridge should always be made on the actual ground. The approaches to a bridge site often involve more work than the construction of the bridge itself. This particularly applies to floating bridges. Tactical bridges may require entirely new approach routes; other bridges should, wherever possible, be sited close to existing routes. Generally a choice of location is possible. The following points should be borne in mind. The channel of a river is in constant state of change due to scouring and silting. The banks are better able to resist scour on straight reaches which are therefore more suitable for new bridge sites; otherwise, protective revetments may be necessary. High banks confine the floodwater in the main channel, and usually mean less work on approaches. Bridges should cross streams as nearly at right angles as possible, since skew spans are usually difficult to erect and also require more piers. Pile piers cannot be used on rocky sites. A straight approach should be sought on each side of the bridge for at least 50 yards. Level approaches are best. If time is limited, the height of the bridge should be such that work on the approaches is reduced to a minimum commensurate with other technical considerations in the design. On the other hand, if damage by the enemy is to be expected, it may be desirable to accept more work on the approaches in order to have a bridge which will be relatively easy to replace.

(2) *Cross section of stream.*—In order to determine the height of the bridge supports, an accurate cross section must be obtained by sounding. If the site is not in the possession of our forces, much information may have to be obtained from an examination of aerial photographs. If these are not available, the span of the gap may be determined by triangulation from the shore in possession of our forces.

(3) *The character of the bottom.*—Often an adequate idea may be formed of the bottom and substrata by driving a pointed spar or light test pile into the soil. Time permitting, a better idea can be obtained by making auger borings. An auger is attached to the necessary length of pipe. This is rotated by hand and withdrawn from time to time to bring up samples. A 2-inch auger is needed for very hard soils.

(4) *Character of the flow.*—Examine existing bridges and any other possible sources of information to determine the floodwater height, as the bridge must be designed to have sufficient clearance for river traffic, and to provide for the passage of floodwater and ice.

(5) *Local materials.*—The reconnaissance should determine the nearest sources of materials which may be used in the construction. The sources include: standing timber of large sizes for the bridge proper; standing timber of smaller sizes which might be used for crib piers or crib abutments or for corduroying the approach roads; nearby buildings from which timbers may be removed; local lumber markets or military engineer depots. The location of these sources is of great importance because of the transportation problem.

(6) *Construction camp.*—The reconnaissance should determine a suitable location for the camp of the constructing forces during the period of the construction. The camp should be located in a concealed area, if possible, as near as possible to the bridge site, and should include space for the storage of engineer supplies, the parking of transportation, rolling kitchens, and latrines. The nearest water supply should be located.

(7) *Security measures.*—The reconnaissance should also take into account all the necessary measures for security against possible attacks against the troops constructing the bridge and the traffic that will lead to or pass the site. Very often most of the necessary measures will merely be to inform the senior commander in the locality or area in which the work is done; in any case sentries should be posted to give warning of air and ground attacks. In case of very important construction, specific requests should be made to higher authority for the necessary protective measures which might include antiaircraft artillery, antimechanized units, other combat troops, or other engineer organizations to erect and defend obstacles where there is danger of mechanized ground attack or local raids. Sentries should be provided to warn against gas attacks. Engineers will seldom, if ever, have the means to provide these security measures, but they should not fail to request whatever is necessary along these lines and to see that it is provided when and where needed.

(8) *Reconnaissance form.*

Bridge at ______________
Class __________________
Sheet No. __ in __ sheets

FORM FOR BRIDGE RECONNAISSANCE

Map reference ____
Date ____________________ Party ____________________________
[If necessary, use back of sheets; repeat number of headings]

LOCATION

(1) Designation of route ____________________________________
(road, railroad, canal, or stream)
(2) Two towns on route _____________________________________
(3) Name of nearest town; direction and distance from bridge ____
____
(4) Stream, canal, road, or railroad crossed by bridge ___________
(5) Local name of bridge ____________________________________
(6) Remarks ____
____

DESCRIPTION OF BRIDGE

(7) Type ____
(8) Spans ____
(9) Total length ____
(10) Net length ____
(11) Total width ____

(12) Width of roadway ____
(13) Clearances:
Above roadway {Horizontal ____________________________ / Vertical ____________________________}
Under roadway ____
(14) Floor system:
(*a*) Flooring ____
(*b*) Stringers and floor beams ________________________
(*c*) Curbs, handrails ________________________________
(15) Number and width of sidewalks ________________________
(16) Piers ____
(17) Abutments ____
(18) Wing walls ____
(19) Paving ____
(20) Maximum loads: Now using bridge ____________________
Reported capacity ________________________________
(21) Remarks ____

DESCRIPTION OF CROSSING

[Make plan and profile on extra sheet showing (*a*) all bridges involved in crossings; (*b*) bridge being reported on]

(22) One of ______ bridges involved in crossing ______________
____
(23) Character of stream. Maximum depth {Low water__________ / High water__________ / Observed__________}
(24) Velocity: Feet per second ____________________________
(25) Floods per year ______ months ________________________
(26) Amount and character of debris carried at high water ______
____
(27) Character of bed and banks of stream ________________
(28) Approaches:
(*a*) ________ end. Straight length ________' width ________ height ________ cut or fill.
(*b*) ________ end. Straight length ________' width ________ height ________ cut or fill.
(29) Remarks ____
____
(30) Description of connecting roadway between several bridges involved in crossing ________________________________
____

RECOMMENDATIONS

(31) List in order of practicability for new construction:
(Pile bents, trestle, crib supports, etc.) ________________
____
(32) Remarks ____
____
(33) Estimate of time required for construction ______________
(34) Troops ____
(35) Bill of materials (use extra sheet) ____________________
(36) Location of construction camp ________________________
(37) Remarks ____
____
____

c. Inspections of existing structures.—The reconnaissance of existing bridges is made to determine the loads allowable. When definite information on the design capacity of the bridge is available and inspection indicates that the bridge has been maintained satisfactorily, the problem is simple. In general, data on design capacity will be obtainable only for major bridges of fairly recent construction. In the majority of cases the only information will be that obtained from the reconnaissance. If the crossing is essential to the plan of the commander, the engineer officer must, without delay, determine the capacity of the bridge, in order to arrive at a decision whether to use the structure as it stands, to reinforce it, or to provide a new crossing. Following is a brief outline of the steps followed in inspecting a structure:

(1) Where the bridge is in territory that has been evacuated by the enemy, the abutments and piers should be carefully examined for evidence of mines. This should be done first.

(2) Examine planking to determine its general condition. It should be smooth, for the reason that a rough surface greatly increases the stresses in all parts of the bridge. For modern heavy loads a simple rule-of-thumb is that the thickness of the planking in inches should never be less than one and one-half times the clear distance between the stringers in feet. Thus, if the stringers are 2 feet apart the floor planks should be at least 3 inches thick. This rule should not be carried to absurd limits in either direction, and should be modified by the statement that whenever the flooring is less than 2½ inches thick it should usually be reinforced by way planks or by a diagonal layer of flooring, regardless of the spacing of the stringers. Splitting and rotting should be noted as evidences of weakness.

(3) Examine stringers at supports for rot or crushing, and throughout their length for warping, twisting, splitting, or breakage. The amount of sound stringers remaining must be decided and figures based on this decision.

(4) Examine pile and trestle bents for rot, splitting, loose joints, and alinement.

(5) Examine wooden abutments and footings for rotting, settlement, and erosion, or sloughing away of the bank beneath them.

(6) Examine masonry abutments and piers for cracks, bulging, or sliding. The change of condition between inspections is of great importance in this connection.

(7) If the floor consists of a paved surface on sound, properly placed buckle plates, it is safe to assume that it will carry the heaviest military loads. If the flooring is a concrete slab, the determination of its capacity will be difficult in the field, but it may be roughly estimated from the capacity of the stringers.

■ 74. DETERMINATION OF ALLOWABLE LOAD.—The inspection having been made, the next step is the determination of the allowable load. As time for a detailed computation is generally not available, a rule-of-thumb for capacity is desirable. If the flooring has been found satisfactory according to the rule-of-thumb given in paragraph 73*c*(2), or can be made satisfactory by the addition of way-planks or doubled planking, the arrangement and strength of stringers is next investigated. Taking into consideration the kind of flooring apt to be found, it is reasonably safe to assume that the load will not be equally divided among the stringers. It is a fair assumption that one-third of the total load upon the span might have to be carried by any one stringer and that two-thirds of this load, that is, two-ninths of the entire load on the span centered in the middle of the stringer, will give an approximately equivalent bending stress. Based upon this hypothesis approximately simple formulas for judging the strength of stringers are—

$$W=\frac{bd^2}{L} \text{ (for rectangular timber)}$$

$$W=\frac{6d^3}{10L} \text{ (for round timber)}$$

where

W=the maximum permissible load on a single stringer in hundreds of pounds

b =the breadth of the stringer in inches

d =the depth of a rectangular stringer in inches, or the diameter of a round timber in inches

L =the span in feet

These formulas are based on a working stress of 1,800 pounds per square inch. The factor of safety is about 3. If judgment indicates that this working stress is excessive for the stringers being investigated, the permissible load should be taken as proportionately less. An approximate formula for judging the strength of a steel I-beam is —

$$W=\frac{d^2}{5L}$$

where

W=the maximum permissible load on a single I-beam in tons

d =the over-all depth of the I-beam in inches

L =the span in feet

Example.—An existing bridge is found to have six rectangular wooden stringers 8 by 10 inches in cross section, evenly spaced at 2 feet from center to center; span 14 feet; floor planks 2 inches thick; What maximum load should the bridge pass?

Solution.—The load which any one stringer can pass is, by the formula given above, $W=\frac{8\times 10\times 10}{14}=57$ hundred pounds.

The floor planks being thin, it is assumed that this stringer may have to carry two-ninths of the total load on the span. Therefore the total permissible load on the bridge is $\frac{9}{2}\times 5{,}700=25{,}650$ pounds. Extra flooring is required.

TABLE XXII.—*Typical and critical bridge loads*

	Description	Gross weight in pounds	Front axle load ①	Intermediate axle load ②	Rear axle load ③	Distance in inches between— ① and ②	② and ③	① and ③
			Pounds					
Bridges built for H-10 (division) loads will carry any of these if vehicles are not overloaded	Men in single file	[1] 140						
	Pack train in single file	[1] 250						
	Cavalry in column of threes	[1] 560						
	Escort wagon, 4-mule	5,000	1,800		3,200			72
	Car, motor, heavy	5,700	1,400		4,300			132
	Truck, 1½-ton	9,000	2,200		6,800			145
	Truck, 2½-ton, searchlight	15,450	4,050	5,700	5,700	150	46	196
	Truck, 3-ton cargo	14,000	3,600	5,200	5,200	132	46	178
	Truck, 4-ton cargo	16,500	6,100	5,200	5,200	142	52	194
	(Towing) 155-mm Howitzer	10,000			10,000			[2] 216
	Tractor, medium M1	16,000						[3] 75
	(Towing) 155-mm Howitzer	10,000	1,000		9,000			[2] 156
	Combat car, M2	19,000						[3] 116
	Balloon winch, type C-2	21,000	9,500		11,500			163
	Shovel, engineer, ⅜-yard	20,000	11,200		8,800			126
	Truck, water purification	20,400	7,000		13,400			162
	Road grader, engineer	21,150	6,750		14,400			227
	Tractor, carrier, engineer	17,000	4,500		12,500			168
	Tractor, carrier, semitrailer	18,900	3,700	7,900	7,300	144	156	300

[1] Per foot.
[2] Distance in inches between axle of towed load and last axle of prime mover.
[3] Length of normal ground contact of crawler tread.

TABLE XXII.—*Typical and critical bridge loads*—Continued.

	Description	Gross weight in pounds	Front axle load ①	Intermediate axle load ②	Rear axle load ③	Distance in inches between— ① and ②	② and ③	① and ③
			Pounds					
Same for H–15 (corps and army) loads	Truck, 7½-ton, 114-inch from, and	34,400	8,000	13,200	13,200	204	52	256
	(Towing) 155-mm gun, M1	30,000	10,000	10,000	10,000	209	46	255
	Truck (AA), 120-inch from, and	35,500	8,500	13,500	13,500	168	48	216
	(Towing) 3-inch AA gun, M2A2	17,000	8,500	-------	8,500	------	------	160
	Tractor, heavy, M1	30,000	-------	-------	-------	------	------	[3] 82
	Tank, light, M2A4 [4]	23,000	-------	-------	-------	------	------	[3] 98
	Truck, field servicing, E-2 (AC)	34,000	7,800	13,100	13,100	169	52	221
	Truck, wrecking, F-2 (AC)	32,000	7,700	12,150	12,150	169	52	221
	Truck, crane, engineer	33,400	10,900	-------	22,500	------	------	181
	Shovel, engineer, ⅜-yard (mounted on trailer)	28,000	11,200	-------	16,800	------	------	216
	Shovel, engineer, ½-yard (mounted on trailer)	38,000	15,200	-------	22,800	------	------	216

[4] Can be carried on H–10 bridge with spans less than 20 feet. Medium tank requires H–20 bridge.

■ 75. STRINGERS.—*a. Arrangement.*—It is of utmost importance that stringers be arranged to take an even distribution of the wheel loads. (See par. 61 and fig. 33.) If the stringers are reasonably well distributed under the load and the floor planks are satisfactory, a safe working assumption is that any one stringer may have to carry 25 percent more than its fair share of the load. If the stringers are not well concentrated under the wheel loads, the distribution of the loads to the stringers must be determined by inspection and the exercise of good judgment. One stringer may have to carry from one-fourth to one-half of the total axle load,

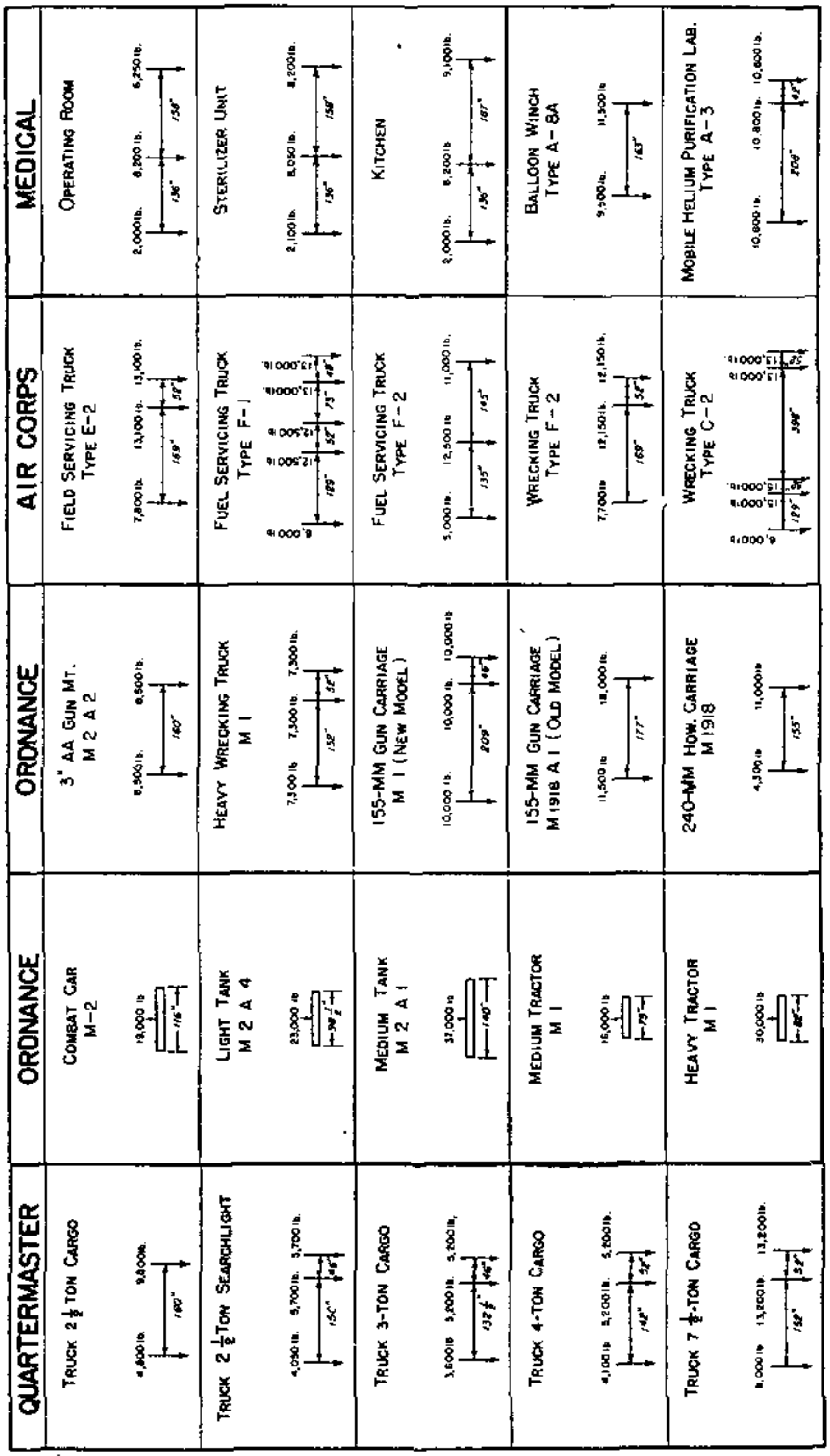


FIGURE 37.—Typical wheel and axle loads.

depending on the thickness of the floor and whether the wheel load is between two stringers or directly over a single stringer. In general, for the worst conditions, the live load supported by stringers should be figured as the reaction of the truck wheels, assuming that the flooring acts as a simple beam between stringers. In any case, the combined load capacity of all stringers should be not less than the total of live and dead loads imposed on the span (i. e., the sum of all the fractions of the loads carried by the stringers must at least equal unity). For the purposes of design only, a more exact assumption for the load distribution to stringers is given in paragraph 63. In any case, the stringer efficiency will be the reciprocal of the ratio of the percentage of the load actually carried by any stringer to the percentage of load which would be carried if the stringers all carried an equal load.

b. Capacity.—The formulas in *c* below give the approximate allowable concentrated load at the center of the span of *simple stringer bridges.* The formulas include an allowance of 25 percent of the live load for impact which is allowed in the case of inspection of bridges but not in the case of the design of military timber bridges as previously stated. The formulas also include an allowance for the dead load of the bridge deck itself. Table XXIII shows the approximate weight in pounds per linear foot of bridge of common types of stringer bridge decks, represented by u in the formulas. The weights for concrete floors are for slab thicknesses of 6 inches; these figures should be increased correspondingly for greater thickness of concrete. In determining dead loads, the weight of timber may be taken as 40 pounds per cubic foot and concrete at 150 pounds per cubic foot.

TABLE XXIII.—*Dead loads of highway bridge decks in pounds per linear foot*

Type of stringer	Wood	Steel	
Type of floor	Wood	Wood	Concrete.
One-way	250–350	250–400	800 up.
Two-way	350–500	400–700	1,300 up.

c. (1) *Rectangular wooden stringers.*—Structural timber varies in allowable fiber stresses according to the kind of timber, condition, etc. The bending stresses usually assumed are 1,000 to 1,800 pounds per square inch. Only that part of the stringer section remaining sound should be considered, and in case of doubt as to the strength classification, the lower limit of the allowable fiber stress should be used. The symbols represent the following:

W=allowable concentrated load in pounds
L =stringer span in feet
f =allowable bending stress in pounds per square inch
d =depth of the stringer in inches
b =total width of stringers of depth d, in inches
u =uniform dead load of span in pounds per linear foot

$$W=\left(\frac{f}{22.5}\right)\frac{bd^2}{L}-\frac{4uL}{10}$$

This formula allows any stress, depending on the kind and condition of the timber, to be used to determine the safe load on one or all stringers depending on the value taken for b. For a quick, rough estimate the second term $\left(\frac{4uL}{10}\right)$ my be neglected.

(2) *Standard steel beams.*—The standard steel beams used as stringers in bridges are I-beams, *CB*-beams, and various other types of cross sections such as channels, and built-up beams consisting of plates and angles. Standard steel sections vary with respect to depth and flange width, thickness of web and flange metal, and weight per linear foot of beam. Where time and tables are available, handbooks should be consulted for detailed computation of capacity. The symbols used in the formulas are the same as those above, with the addition of N which refers to the number of I-beams in the section.

(*a*) For standard I-beams of *minimum* web thickness—

$$W=930\frac{Nd^2}{L}-0.4uL$$

(*b*) For standard I-beams of *average* web thickness—

$$W=1050\frac{Nd^2}{L}-0.4uL$$

In the absence of a handbook to determine whether the I-beams have minimum or average web thickness, it is safer to use the formula based on minimum web thickness. The strength and weight per foot of length of I-beams of minimum thickness are shown in able XVII.

d. Efficiency factor.—The formulas in *c* above should be modified whenever it appears that the stringer distribution is such that all stringers do not bear approximately equal shares of the load. This modification may be made by multiplying the expression $\frac{d^2}{L}$ on the right side of the equation by a factor such as 0.7, 0.8, or 0.9 selected as representing the stringer efficiency. This stringer efficiency factor represents the percent of stringers which are effective in carrying their full pro rata share of the load.

e. Uniform live loads.—When the live load on the span is a uniformly distributed load, as in track-laying vehicles, the capacities may be increased above the figure as determined in *b* above. The total capacity is expressed in the formula below in which—

U=total uniformly distributed safe load in pounds

T=length of track in contact with the floor, in feet

W and L are used as in the previous formulas

$$U=W\left(\frac{2L}{2L-T}\right)$$

Thus, when the track covers the entire span ($T=L$), the actual capacity of the span is double the amount as computed for a concentrated load. When the track length exceeds the span, the capacity computed is for that part of the vehicle actually on the span. The capacity of existing bridges may also be checked rapidly and reliably by means of the diagrams given in figures 35 and 36 by reversing the normal steps in the use of the chart.

f. Shear and bearing.—In addition to bending stresses, forces acting on the bridge tend to shear the stringers and to crush them at the supports. Application of the bending stress formulas to the bridge spans used in common practice, including the relatively short spans used in military engineering, generally provides stringer sections fully adequate to bear the maximum shearing and bending stresses developed in the stringer section. Referring to table XVIII, however, it will be seen that for very short spans, shear may be the controlling factor. A seat with bearing surface 6 inches or more wide is generally adequate to transmit the maximum load from a stringer to the cap or bank seat without the occurrence of crushing in either member. For these reasons, consideration of shear and bearing stresses is omitted from this section. When investigation of a bridge discloses unusually short spans and correspondingly light stringer sections, or when any members show signs of partial failure, shear and bearing stresses should be accurately determined by the methods given in section II.

■ 76. SUPPORTS.—*a. General.*—As a general rule, it may be assumed that the supports of any bridge have been constructed to carry the maximum loads that may be placed on the spans they support. For this reason their strengths need not be investigated when the capacity of the spans is not to be exceeded and if they are structurally sound. When the spans are reinforced to increase their capacity it may be necessary to reinforce the supports as well. In some cases the bridge supports may have a capacity considerable in excess of the spans, as when a light superstructure, sufficient for present needs, is erected on heavy piers planned to carry heavier spans at some later date.

b. Types.—The common types of bridge supports are concrete or masonry piers carried on bed rock, hardpan, grillage, or pile foundations; trestle bents or piers resting on hardpan or footings; pile bents or piers; and crib piers. Masonry piers may be assumed as adequate for all military loads except when they show signs of failure under existing loads. In these cases new supports may have to be constructed and the span load transferred to them. The capacity of crib piers is not readily determined from inspection. The capacity of these may be assumed as that of the cap supporting the spans, or an approximation made from the bearing value of the soil supporting them.

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c. Trestles.—The allowable load on a timber used as a column depends on the unsupported length of the column, its least dimension, cross-sectional area, and the kind of timber used. The maximum allowable fiber stress in compression in the more common structural woods ranges from 1,000 to 1,500 pounds per square inch. The maximum fiber stress in compression must be reduced according to the length and least diameter of the member. The total safe load (P) on a column is found by the formula—

$$P=p\ A, \text{ in which—}$$

A=the cross-sectional area of the column in square inches
p=the safe unit working stress for the column

$$p=s\left(1-\frac{L}{60d}\right), \text{where}$$

s=the allowable unit, end-bearing stress (compression parallel to the grain)
L=the length of column in inches
d=the least side or diameter of the column, also in inches

For military loads, the ratio, $\frac{L}{d}$, should not exceed 40.

Table XXIV provides a quick means of determining safe loads for certain square posts without recourse to the formula.

TABLE XXIV.—*Safe loads, square posts, and for various values of* $\frac{L}{d}$

[Fiber stress assumed to be 1,200 in the formula. Proportionate increases or decreases should be used for higher or lower stresses]

Size (inches)	Length (feet)	$\frac{L}{d}$	Safe unit working stress for post	Safe load for post
4 by 4	2	6	1,080	17,280
4 by 4	4	12	960	15,360
4 by 4	6	18	840	13,440
4 by 4	8	24	720	11,520
4 by 4	10	30	600	9,600
6 by 6	4	8	1,044	37,440
6 by 6	6	12	960	34,560
6 by 6	8	16	880	31,680
6 by 6	10	20	800	28,800
6 by 6	12	24	720	25,920
6 by 6	14	28	640	23,040
6 by 6	16	32	560	20,160
8 by 8	6	9	1,020	65,280
8 by 8	8	12	960	61,440
8 by 8	10	15	900	57,600
8 by 8	12	18	840	53,760
8 by 8	14	21	780	49,920
8 by 8	16	24	720	46,080
8 by 8	18	27	660	42,240
8 by 8	20	30	600	38,400
8 by 8	22	33	540	34,560
8 by 8	24	36	480	30,720

d. Piles.—The capacity of existing piles cannot be determined accurately unless test piles are driven in the same locality and their capacity developed by loadings. For ordinary purposes it may be assumed that piles of 1 foot mean diameter driven to the usual depth, have capacities of from 2 to 5 tons in mud and soft clay, 7 to 22 tons in stiff clay, 8 to 24 tons in compact sand, and 10 to 30 tons in sand and gravel. (See also Table XXI.)

■ 77. TRUSSES.—*a. Definitions.*—A truss bridge is one in which the roadway loads are transmitted from the floor system to the bridge abutments or piers by means of a truss.

A truss is in effect a compound beam, the parts of which are arranged to form one or more triangles in the same plane. In theory, truss members are subjected to longitudinal stresses (compression or tension) only. The components of a truss are the top chord (line of top members), the bottom chord (line of bottom members), and the web (intermediate verticals and diagonals). Top chord members are always in compression and bottom chord members are always in tension, except in cantilevered trusses, in which these stresses are reversed. Web members are either in compression or tension, according to their position and the type of truss. The divisions of the total span between the points where loads are transmitted to the truss are termed panels. In order to prevent reversal of stress in web members, as a load moves across the bridge, secondary diagonal members known as counters are inserted in panels as needed. The loads on a truss are transmitted by the stringers to the floor beams on which the stringers rest. The floor beams transmit the loads to the truss at the intersections (called panel points and referred to above) of the web and chord members. The dead loads on the truss (weight of flooring, trusses, etc.) are constant loads always acting at the panel points. The live loads moving on the truss are applied at one or more panel points, depending on the length and character of the loads. The common types of trusses are king post (known as trussed beam when inverted), queen post, Howe, Pratt, and Warren. These types are illustrated in figure 38. In the diagrams compression members are indicated by heavy lines, tension members by light lines, and counters by broken lines. Through bridges have loads carried on the lower portions of the trusses with overhead bracing; pony trusses are similar, but there is no overhead bracing. Deck bridges carry the loads on the top portions of the trusses.

b. Conditions of maximum stress.—The maximum stresses in the top and bottom chord members of a truss occur when the bridge is loaded by the live load to produce maximum bending, that is, when the load covers the entire bridge.

The maximum stresses in the web members occur when the bridge is loaded by the live load to produce the maximum shear at the section considered, that is, when the load covers the greater portion of the bridge with the head at, or as near as possible to, that section.

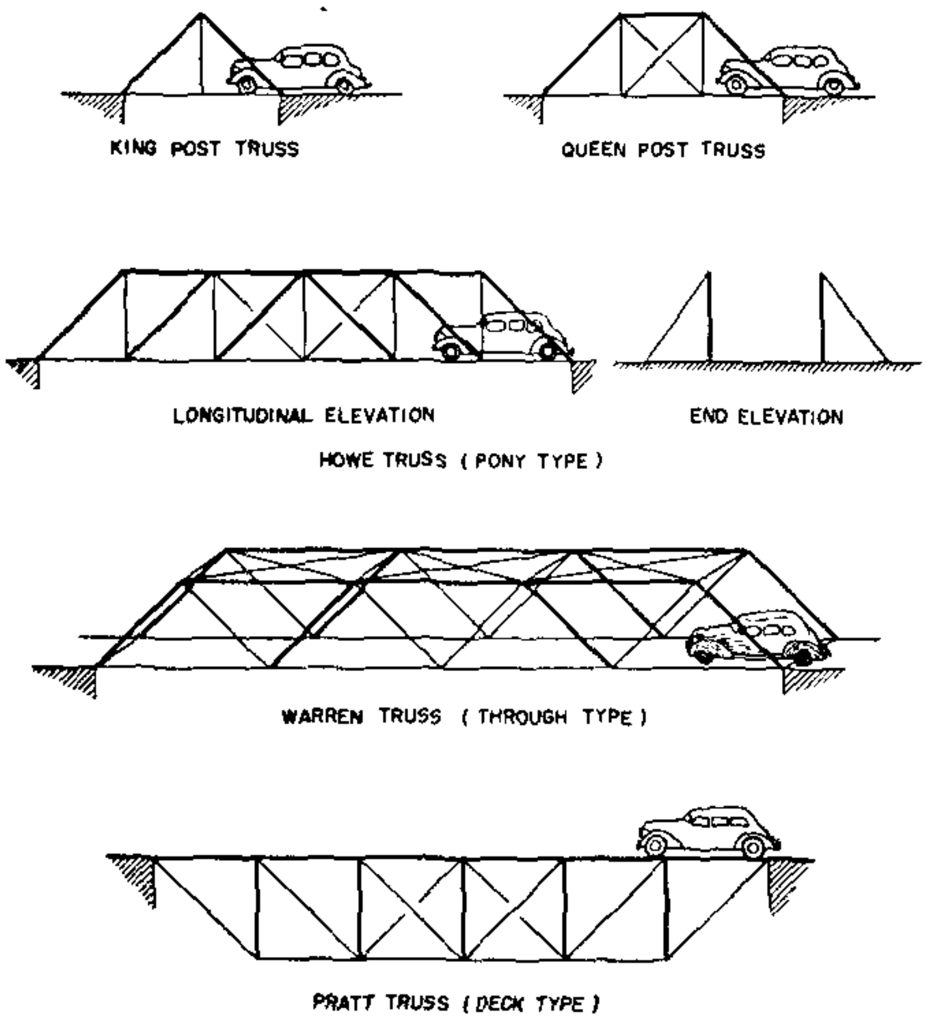

FIGURE 38.—Types of trusses.

c. Use of trusses.—Trusses are used for spans of such length that great strength would be required in a simple beam or girder. Trusses are economical of materials, but require time for design, assembly, and erection. Their use in military operations is limited to special cases. In the forward areas of the combat zone, standard portable steel trusses are sometimes used, as in cases in which use of simple bridge types is prohibited by depth of stream, clearance requirements, or length of required span.

d. Resolution of stresses.—In order to satisfy the conditions of equilibrium, the forces (whether external or internal) acting on a structure, or any part thereof, must balance. This condition is commonly expressed by the following statements relative to all forces acting at any point:

The sum of all the vertical component of all forces $=\Sigma V=O$.

The sum of all horizontal component of all forces $=\Sigma H=O$.

The sum of all moments of forces about the point $=\Sigma M=O$.

A moment of a force about a point is the product of the force times the perpendicular distance from the point to the line of action of the force. Moments are expressed in inch-pounds, foot-tons, etc., depending on the units used for the values of the distance and of the force. The reactions at the supports must always be determined in order to find the stresses in a truss. This may be done as described in paragraph 59 or by taking moments of all the external forces acting on the truss, including the reaction at one support about the other support as a center of moments. By equating these moments (using proper signs) and solving, the unknown reaction may be found. The other reaction may be found by deducting the reaction just found from the sum of all loads on the truss. The application of these principles can be best illustrated by a number of simple problems which follow.

■ 78. ILLUSTRATIVE PROBLEMS.—*a. King post truss.*—(1) *Statement of problem.*—The king post trusses of a one-track bridge are found to have a span of 24 feet and a height of 9 feet. All members are of 6– by 6–inch timbers except the verticals (one in each truss), which are 1½-inch round steel rods. It is necessary to find out whether the bridge will carry a total concentrated load of 30,000 pounds, including live and dead loads and impact.

(2) *Solution.*—The load on each truss is one-half of 30,000 pounds, and the reaction at each support is one-half this, or 7,500 pounds. The truss is composed of two equal, right angle triangles placed back to back, the hypotenuses of which are equal to $\sqrt{12^2+9^2}=15$ feet.

Then: Compression in top chords necessary to produce vertical compressions of 7,500 pounds is $7{,}500\times\frac{15}{9}=12{,}500$ pounds. The horizontal component of this is $12{,}500\times\frac{12}{15}=$ 10,000 pounds. Tension in the vertical must counteract the vertical components of the two upper chords, hence equals $2\times7{,}500$ or 15,000 pounds. Assume allowable stresses for the timber members as follows:

Tension, $f_t=1{,}600$ pounds per square inch
Compression, $s=1{,}200$ pounds per square inch
Modulus of elasticity=1,600,000 pounds per square inch

Referring to table XXIV, it is seen that square posts (6″×6″) of 15-foot length will sustain a safe load of between 20,160 and 23,040 pounds, hence they are safe for 12,500 pounds. Bottom chords, having cross-sectional areas of 36 square inches, will carry $36\times1{,}600=57{,}600$ pounds, and hence are safe for 10,000 pounds even after notching for joints, drilling bolt holes, etc. From table XXV it is seen that a 1½-inch rod has a cross-sectional area of 1.29 square inches. This will support $1.29\times18{,}000=23{,}220$ pounds, hence is safe for 15,000 pounds. For the solution of a problem of design the reverse of the above processes would be used.

TABLE XXV.—*Sizes of threaded, round bars, nuts, and washers (United States standard)*

Diameter of bar	Net diameter	Net cross-sectional area at base of thread	Short diameter of nuts	Washers		
				Diameter bolt hole	Diameter of washer	Thickness of washer
Inches	*Inches*	*Square inches*	*Inches*	*Inches*	*Inches*	*Inches approx.*
3/4	0.620	0.30	1 1/4	13/16	2	0.134
7/8	.731	.42	1 7/16	15/16	2 1/4	.15
1	.838	.55	1 5/8	1 1/16	2 1/2	.15
1 1/8	.939	.69	1 13/16	1 1/4	2 3/4	.15
1 1/4	1.064	.89	2	1 3/8	3	.15
1 3/8	1.158	1.05	2 3/16	1 1/2	3 1/2	.15
1 1/2	1.283	1.29	2 3/8			
1 5/8	1.389	1.51	2 9/16			
1 3/4	1.490	1.74	2 3/4			
1 7/8	1.615	2.05	2 15/16			
2	1.711	2.30	3 1/8			
2 1/4	1.961	3.02	3 1/2			
2 1/2	2.175	3.72	3 7/8			

b. Queen post truss.—A queen post truss having a span of 30 feet and truss height of 10 feet is to carry loads, including live and dead loads and impact, as shown in figure 39.

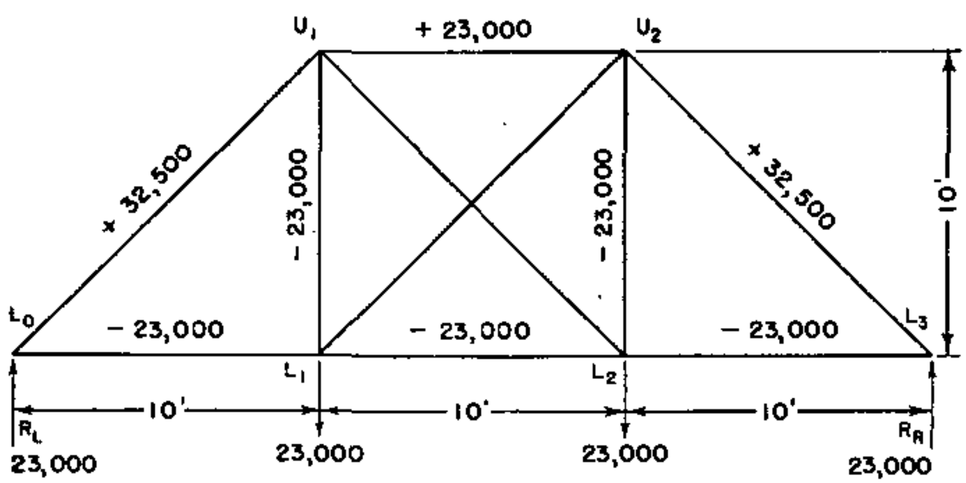

FIGURE 39.—Truss stresses—moments of force.

Inspecting this truss, it is seen that the top chord, $L_0U_1U_2L_3$. is in compression, the bottom chord, $L_0L_1L_2L_3$, in tension, and the vertical posts, U_1L_1 and U_2L_2, are in tension. Length of members L_0U_1, L_1U_2, U_1L_2, and U_2L_3 is—

$\sqrt{10^2+10^2}=14.14$ feet
Reaction $R_L=R_R=23{,}000$ pounds
Sum of vertical components at $L_0=0$:

Stress in $L_0U_1=23{,}000\times\frac{14.14}{10}=32{,}500$ pounds (approx.) compression. The horizontal component of $L_0U_1=L_0L_1=R_L=$ 23,000 pounds, or by making the sum of moments about $U_1=0$—

$$\text{Stress in } L_0L_1=\frac{23{,}000\times10}{10}=23{,}000 \text{ pounds tension.}$$

Omitting L_1U_2 from the panel, the stress in U_1L_1 is 23,000 pounds tension. Since the vertical component of L_0U_1+ 23,000, plus the vertical stress in U_1L_1—23,000, equals 0, there can be no stress in U_1L_2. With no stress in U_1L_2, the stress in U_1U_2 must be equal and opposite to the horizontal component of stress in L_0U_1, the stress in U_1U_2 being then 23,000 pounds compression. By analogy, the stresses in the remaining members are the same as in the corresponding members computed. The web members U_1L_2 and U_2L_1 are not stressed when the truss is symmetrically loaded. To find the stress in these members, it is necessary to determine the worst condition of unsymmetrical loading, that is, when the maximum shear occurs. Neglecting the dead load, we may assume that the stresses on the truss are caused by moving loads of 23,000 pounds each, with 10 feet between the loads. The worst condition will then occur when one load is at L_2 and the other at L_3. As the dead load has been neglected, this will be slightly worse than the actual critical condition. If we consider the loading to be due to a uniform load of 2,300 pounds per foot, the maximum shear will occur when the truss is uniformly loaded from L_2 to the middle of the center panel only.

c. Truss stresses by the method of index coefficients.—For any given or assumed loading this is a rapid method of determining the stresses in any member of a truss by inspection, as shown in figure 40.

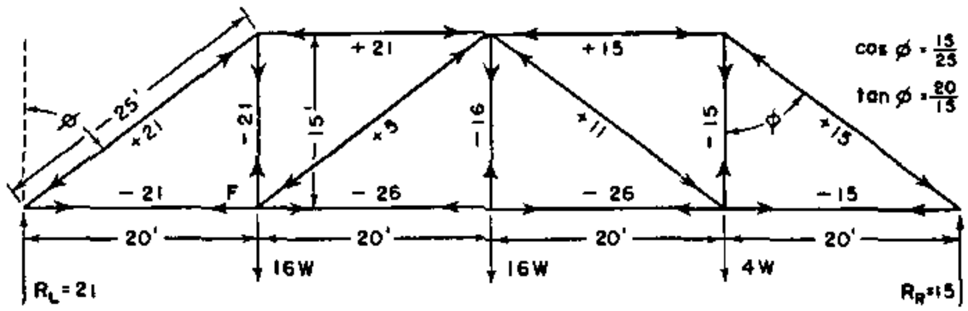

FIGURE 40.—Truss stresses—index coefficients.

$$\text{First find } R_L = \frac{3(16)}{4} + \frac{16}{2} + \frac{4}{4} = 21$$

$$R_L + R_R = 36$$

$$R_R = 36 - 21 = 15.$$

The absolute coefficient of any diagonal web member is the shear in that panel found by taking the algebraic sum of external loads and reaction from either support to that panel $(16+16-21=11=15-4)$. Note that at every panel point (as at F) the algebraic sum of the upward coefficients $(+5-21=-16)$ = the sum of the downward coefficients (-16) and the sum of the coefficients to the right $(+5-26)$ $=-21=$ the sum of coefficients to the left (-21). Compression and upward reactions are + and tension and downward forces are —, as will be noted for all reactions and top chords and loads and lower chord members, respectively. Compressive stresses (in a plus member) are considered to act toward both ends and tensile stresses (in a minus member) away from both ends toward the center. This may be shown by arrowheads or two colors for convenience. Actual stresses are found by multiplying the coefficients of inclined members by $\frac{W}{\cos \phi}$, horizontal members by $W \tan \phi$ and vertical members by W, which in this case would be $\frac{25W}{15}$, $\frac{20W}{15}$, and W, respectively. W may be any convenient unit, such as tons, 100 or 1,000 pounds, panel loads, etc.; ϕ is the angle the inclined members make with the vertical.

■ 79. SUSPENSION BRIDGES.—*a. General.*—Suspension bridges are rapidly constructed and are practical for long spans (i. e., spans over 100 ft. in length) and light loads. They are chiefly used when the gap is too deep or the current too swift to make pier supports practical. In military operations they may be utilized in mountainous or uncivilized country where the general lack of communications is such that the expedition is equipped with only animal or light mechanical transport. The location of the suspension bridge site is, in general, governed by the tactical and technical considerations. As the stability of the suspension bridge is largely dependent on the anchorage, a site should be selected where the banks are of solid rock or earth and at about the same level. The following subparagraphs indicate a method of determining the capacities of existing bridges and furnish clues to the design of new structures.

b. Capacity of cables.—The formulas for determining stresses in cables are:

(1) For a uniform load:

$$T=\frac{\frac{S}{2}}{\sin\theta}=\frac{S\times\sqrt{L^2+16d^2}}{8d}$$

(2) For a concentrated load:

$$T=\frac{1}{2}\sqrt{S^2+\left[\frac{L}{4d}(S+W)\right]^2}$$

where

T=the maximum cable tension (in all the cables at one tower).

W=the concentrated live load on the bridge.

S=the sum of all live and dead loads on the bridge cables (including impact and all other loads).

L=the span in feet between towers.

d=the deflection (sag) of the cable in feet at midpoint below tops of towers.

θ=the angle made with the horizontal by the tangent to the cable at the tower.

The formula for the tension, T, resulting from a concentrated load gives only approximate results because of the fact that the concentrated load, W, if large, will change not only the deflection, d, but also the angle θ. This change in deflection will produce serious distortions in the floor system. For this reason the floor system, or the stiffening truss, should have sufficient rigidity to distribute the concentrated load over several panels so that the concentrated load will, in effect, act like a distributed load, in which case formula (1) applies. The abutments at the ends of the roadway support a portion of the loads on the end panels. The reaction at the abutments due to the total of all loads on the end panels should be considered when calculating stresses in the bridge.

(3) The length of cables between towers is given by the formula:

$$L+\frac{8d^2}{3L}$$ (approximation based on a circular curve)

This approximation is quite accurate if the sag does not exceed $\frac{1}{10}$ of the span. The angle between the direction of the cable at the tower and the horizontal, expressed in terms of its tangent, is $\frac{4d}{L}$.

c. Materials of construction.—Cables are commonly made of steel wire rope or chain. Hemp or manila rope may be used. Table XXVI gives the working strengths of various sizes of steel wire rope and of hemp or manila rope.

TABLE XXVI.—*Working strength of wire and hemp rope*

Diameter	Circumference	Weight per 100 feet		Working strength (pounds)	
		Steel	Hemp	Steel	Manila or hemp
⅜	1¼	13	5	4,000	400
½	1½	39	7	7,000	850
⅝	2	60	13	11,100	1,520
¾	2⅜	88	17	15,300	1,900
⅞	2¾	120	24	20,700	2,300
1	3⅛	158	28	28,000	3,100
1¼	4	250	46	42,000	4,300
1½	4¾	365	64	58,700	5,900
1¾	5½	525	84	76,000	7,900
2	6¼	632	115	96,000	10,300
2½	7⅞	988	117	110,000	16,500
3	9½	1,421	255	116,000	22,500

d. Slings.—The length of slings from point of attachment to the horizontal plane through the lowest point of the cables may be determined from the formula: $y=\left(\frac{4d}{L^2}\right)x^2$ in which y=length of the sling, x=distance from the middle point of the bridge to the sling, and d and L are as used above. The center (shortest) sling should have a length of about 1/50 of the span. The above formula does not include any allowance for the camber usual in a suspension bridge roadway, nor the additional length of the shortest sling. In order to determine the true length of slings, it is necessary to adjust the value of y for the camber as separately computed, length of shortest sling, position of point of connection between slings and floor beams, and horizontal spread of cables in excess of distance between floor beam sling connections.

e. Anchorages.—Various means to anchor the backstays are employed. If ledge rock is adjacent to the bridge, an excellent anchorage may be made by setting anchors in the rock. In emergency, and for a light suspension bridge, deadman anchors may be used. The holding power per square foot of loamy earth against a deadman at various depths and inclinations of cable pull is given in table LXVII and the methods of using this table and computing the size of the deadman for safety in bending are given in paragraph 246 *b* (3).

f. Towers.—When the backstay makes the same angle with the tower as does the cable, the tower reaction is vertical and is equal to the total weight of the bridge span plus load. If the angles are unequal, the tower reaction is not vertical and the tower must be able to resist the horizontal component, which may be determined graphically or by computation. When a concentrated load comes upon a light suspension bridge the angle θ changes and the relation between it and the backstay angle will be changed. Therefore, the towers of all light suspension bridges should be strutted (or guyed) to prevent overturning. No guys are needed if the cable and backstay are made fast at the top of the tower as is sometimes done for light bridges. Normally the tower caps or cable seats are designed so that the cable is free to move longitudinally, and accordingly the tension in the backstay is the same as that in the suspension cable.

■ 80. Tabular Summary.—The factors commonly employed in connection with the design or inspection of a military bridge are summarized in the following table:

Table XXVII.—*Summary of bridge factors*

	Design of new bridge	Examination of existing structures
Safety factors:[1]		
Wood	3.0	4.0.
Steel	1.75	2.2.
Impact allowable:		
Wood	None except 25 percent for abutments.	25 percent.
Steel	$I=\frac{25}{(L+125)}$	$I=\frac{25}{(L+125)}$ (may use 25 percent for small bridges).
Stringer efficiency (same for both wood and steel, except in large and important bridges).	90 percent (even number of stringers well distributed). 80 percent (odd number of stringers well distributed).	80 percent (if reasonably well distributed; otherwise less, based on any one carrying more than its proportional share).
Dead load	Compute (first assuming a dead load and checking back on it).	Generally assumed from data in field manual (or computed if time permits).

[1] In designing large and important bridges which may be used over protracted periods, it will be better to employ the factors of normal civil practice.

SECTION IV

SUMMARY

■ 81. SUMMARY.—*a*. Bridges are the most sensitive points on routes of communication and as such must be given adequate attention.

b. Do not build more strongly or elaborately than is necessary in any situation.

c. Make full use of locally available materials and improvise when possible.

d. Use standard timbers and steel in design.

e. Care in the selection of a bridge site will save labor in construction of both the bridge and the approach roads.

f. Do not build a new bridge where an old one can be reinforced to serve the purpose.

g. Keep in mind the loads for which your bridge is being built.

CHAPTER 3

STANDARD MILITARY BRIDGES

SECTION I

GENERAL

■ 82. NEED FOR STANDARD MILITARY BRIDGES.—*a*. The construction or repair of military bridges may occur under a wide variety of conditions ranging from those incident to active operations in the combat zone to those peculiar to the situation in the communications zone. In forward areas bridges capable of carrying divisional loads will often be constructed at night and usually under hostile fire. Wherever there is need for new bridges or the repair or reinforcement of existing ones, speed of construction is essential.

b. To meet possible contingencies, several standard types of military bridges have been developed, and the necessary material for their construction is either issued or kept in depots ready for use.

■ 83. DESIGN.—Design is based on required military necessity for all construction in war.

a. *Simplicity* in design is essential to facilitate transportation construction and repair by partially trained and fatigued troops in the minimum of time.

b. *Economy of materials* necessitates standardization on the minimum number of types consistent with probable needs, minimum design factors for each type, the use of materials easily obtainable, and the elimination of all nonessentials.

c. *Type plans*, drawn up in advance, standardize procurement, stockage of depots, requistioning, and the training of troops in erection.

d. Expansion to handle greater loads is made feasible by providing a type of equipment to handle each major load group and by designing equipment so that it can be easily reinforced.

■ 84. STANDARD TYPES.—*a. Types.*—(1) *Floating bridges.*—(*a*) *Footbridge.*—The model 1935 footbridge obtains buoyancy from sealed metal canisters (or expanded rubber blocks) contained in suitable frames.

(*b*) *Light ponton bridge.*—This bridge (model 1938) has a normal capacity of 10 tons, but can be reinforced with extra boats and balk to carry loads up to 20 tons. Several units of a 7½-ton bridge (model 1926), reinforceable to 15 tons, will continue in use until replaced by the newer model to which it is similar.

(*c*) *Heavy ponton bridge.*—Loads up to 23 tons can be carried on the heavy ponton bridge (model 1924), which is reinforceable to about twice its normal capacity.

(2) *Nonfloating bridges.*—(*a*) *Standard timber trestle bridge.*—This is a simple timber trestle bent bridge with wooden stringers in spans not exceeding 15 feet and steel I-beam stringers in spans over 15 feet but not exceeding 25 feet. The official designation of this structure is "Multiple Short Span (Nonfloating) Bridge for Corps and Army Loads (H–15 Loading)."

(*b*) *Portable, H–10, truss bridge.*—This is a steel bridge of prefabricated, 12-foot, latticed sections, designed for 10-ton highway loads and capable of being assembled by manpower alone in spans of from 24 to 72 feet. Its two girders will carry the H–20 (Highway, 20-ton) loading on spans not exceeding 36 feet. Full title of the equipment is "Portable Single Span (Nonfloating) Bridge Equipage for Division Loads (H–10 Loading)."

(*c*) *Portable, H–20, truss bridge.*—This bridge is similar to the H–10 bridge except that its heavier 12½-foot sections will carry heavier than H–20 loads on spans up to 125 feet.

b. Drill, organization of details, specific care of equipment, etc.—Detailed discussions under these headings are contained in TM 5–270, on this general subject.

SECTION II

FLOATING BRIDGES

■ 85. FOOTBRIDGE EQUIPMENT, MODEL 1935.—*a. List of equipment.*—The normal use of this equipment is to provide a footbridge. It is convertible into a wider bridge suitable for the passage of light vehicles not exceeding 2,500 pounds in weight, but this use will be exceptional. A unit of the equipment affords 432 feet of footbridge, or 144 feet of wide bridge. Three 432-foot units are carried by each light ponton company.

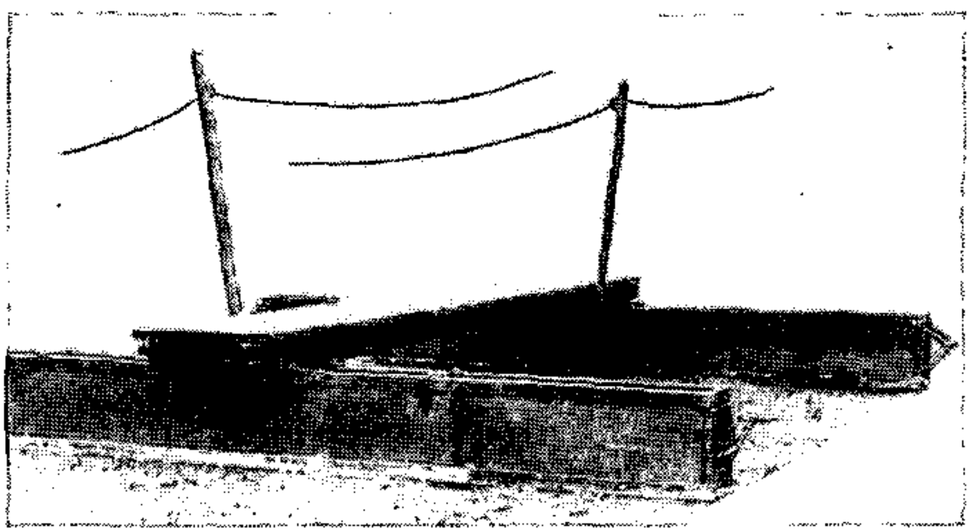

FIGURE 41.—The footbridge equipment, model 1935.

b. Transportation by truck.—The standard load for a 1½-ton truck is 9 bays or 108 feet of footbridge. Four of these trucks are required to transport one unit of the equipment. Somewhat greater loads can be carried in an emergency, but the truck then becomes overloaded and top-heavy. Correspondingly greater amounts can be carried on larger trucks.

c. Description.—(1) A single bay of footbridge consists of one duckboard, two floats, and two handrail posts. (See fig. 41.) It requires 3 bays to construct a wide bridge.

(2) The *duckboard* is of white pine, 12 feet long by 22

inches wide, and weighs about 100 pounds. The duckboards and the bays of bridge are coupled together by one male and one female fastener on each end of the duckboard.

(3) The *float* is a framework of white pine containing expanded rubber blocks (or cans) which give it a net buoyancy of about 400 pounds. Flat-folding carrying handles are provided at each end. The connection between duckboards and floats is made by a spring fastener attached to the top of the float with a hinge shank which is hooked over each duckboard stringer. (See fig. 42.)

(4) The *handrail post* is aluminum, with a bronze lug at the top to serve as receiver for the handrail line and as a tool for disengaging the duckboard fasteners. It is placed at alternate intervals on each side of the bridge floor.

(5) The *anchor cable, bridle lines,* and *guy lines* are provided to guide the bridge during construction and to hold it in place when built, as required under various conditions. The *float cable* prevents the upstream end of the floats from submerging in a swift current. *Pickets* are provided for holdfasts.

d. Care.—(1) All parts of the equipment should be carefully inspected at appropriate intervals, any broken or damaged parts repaired or replaced, and all parts cleaned, painted, and greased as required. Standard olive-drab paint is suitable for those parts of the equipment requiring paint.

(2) Special care should be taken in disassembling the bridge to avoid abuse of the duckboard fasteners and the wooden parts. There is much less danger of damage in the disassembling operation if each bay is removed from the bridge while it is still afloat.

e. General method of construction.—The most rapid, effective, and practicable method of construction is by successive bays (fig. 46). This means that single bays are assembled, connected to the completed portion of the bridge, and successively pushed out into the water. The completed portion of the bridge is held in place and guided by guy lines, or anchor cable, as circumstances may require. A variation of this method is successive construction by sections of two or more bays. This method requires more working room and more men with more skill, organization, and training than the one with single bays. With especially favorable conditions in the vicinity of the bridge site the bridge may be assembled on land, carried forward, and launched in a unit as an assault bridge. The bridge has little lateral flexibility, so that this method is impracticable when brush, trees, rough ground, or steep banks adjoin the bridge site. It is also impracticable over wide or swift

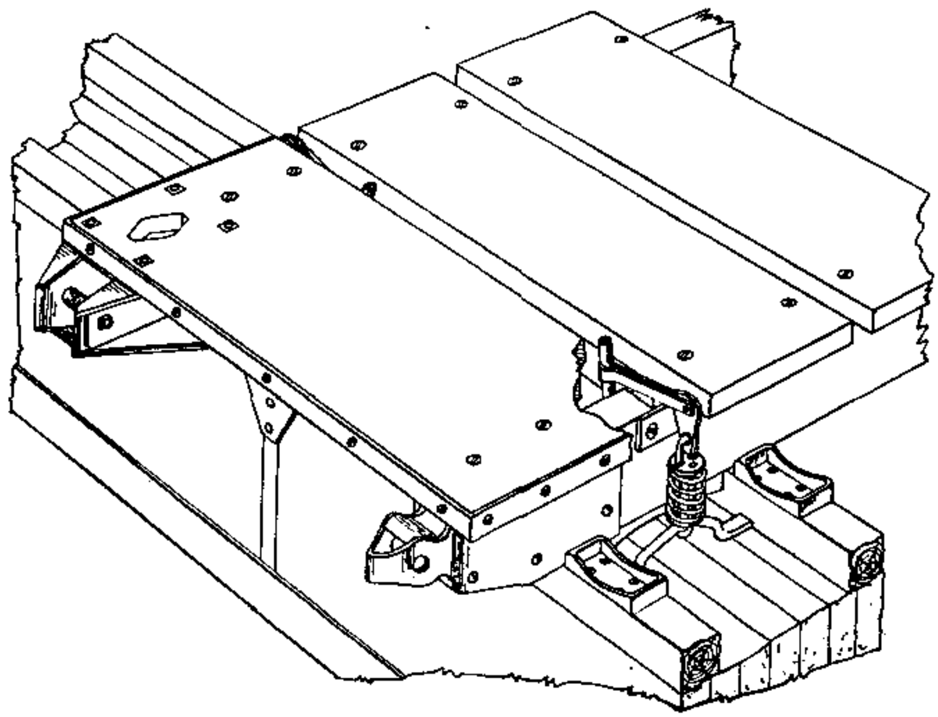

FIGURE 42.—Fasteners between duckboards and floats.

streams. Its chief application would be for the quick and surprise placing of bridges across narrow and placid waterways, such as canals or small ponds. The anchor cable (fig. 43) is necessary when the stream is wide or the current considerable, being connected to the bridge by the bridle lines. The float cable passes through the opened upstream carrying handles of the floats and prevents the upstream ends of the floats from submerging and overturn-

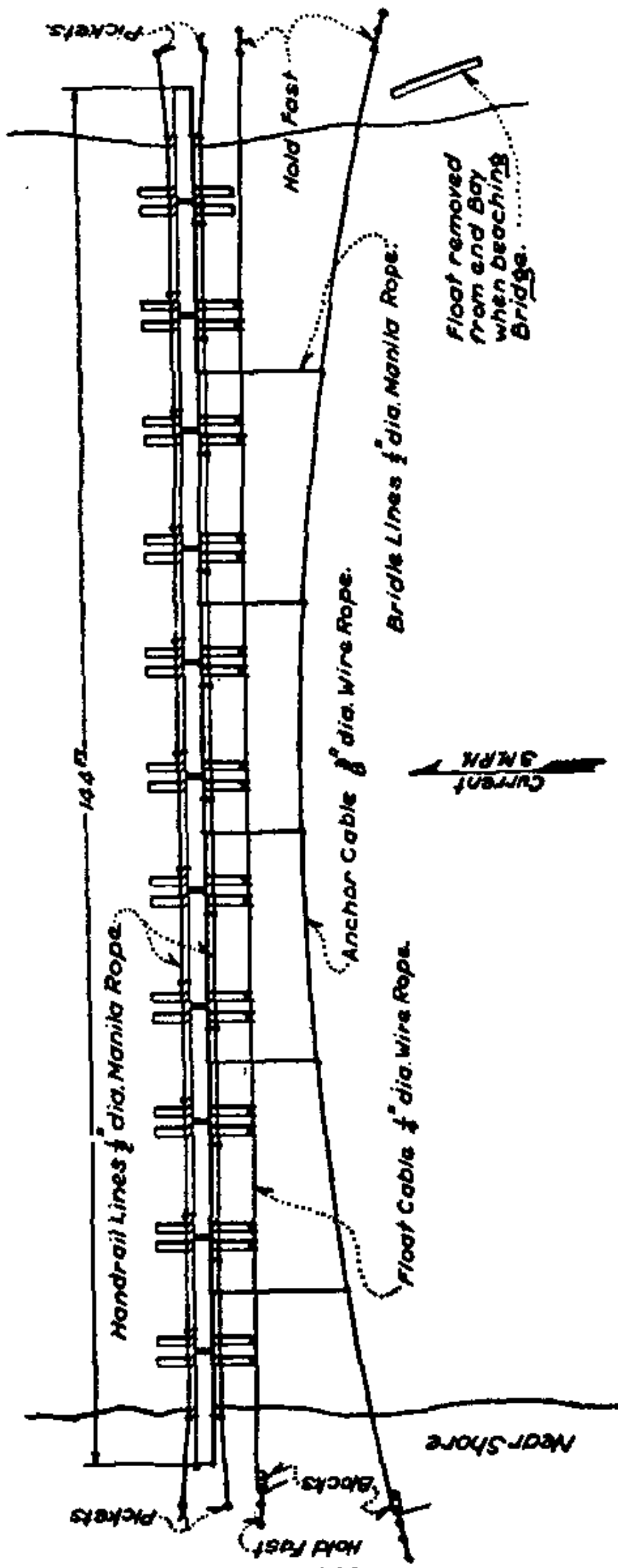

FIGURE 43.—Assembled footbridge using anchor and float cables.

ing the bridge under certain conditions of stream width and current. With less severe conditions, only the guy

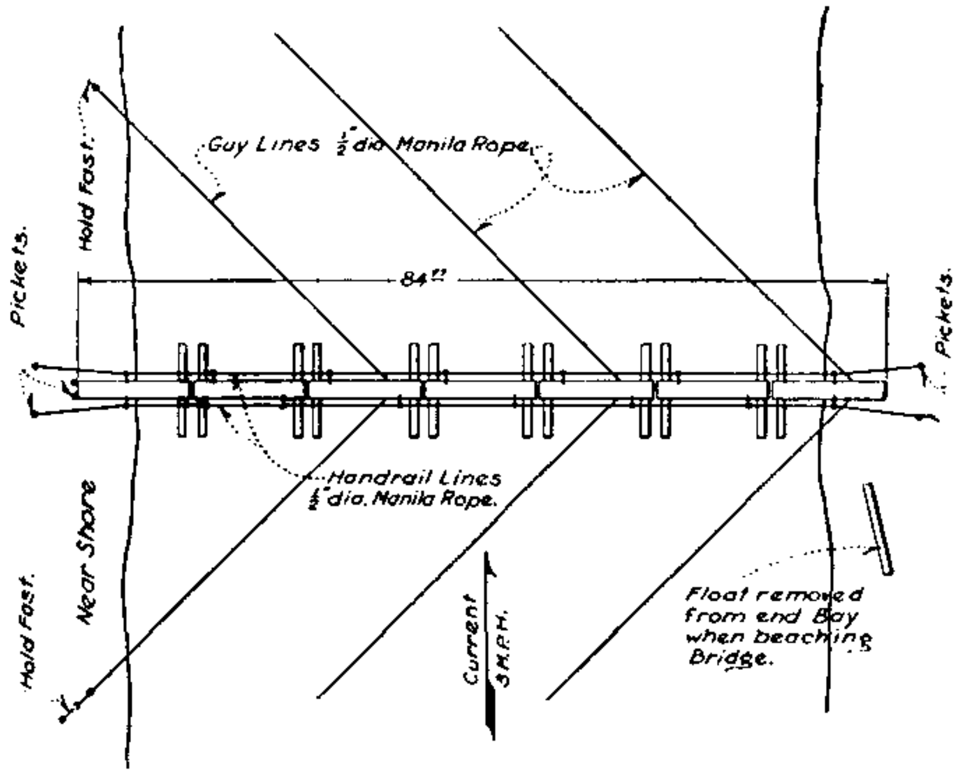

FIGURE 44.—Assembled footbridge using guy lines.

lines (fig. 44) are required to guide the bridge into place and hold it after it has been built.

TABLE XXVII.—*Data on cables and lines for footbridge*

(Not applicable to cartbridge)

Current in main channel of stream	Maximum practicable bridge length with anchor cable	Anchor cable required for bridge length over	Bridle lines anchor cable to bridge	Float cable required for bridge length over	Guy lines required both sides bridge to bank when anchor cable not used
Miles per hour	*Feet*	*Feet*		*Feet*	
0	1,000	500	Each 10 bays	0	Only required over 100 feet. 100–300 feet at end. 300–500 feet at end and center.
1	700	300	Each 6 bays	300	Less than 100 feet at end. 100–300 feet at end and each 6 bays.
2	500	200	Each 4 bays	200	At end and each 4 bays.
3	350	100	Each 2 bays	100	At end and each 2 bays.
4	200	(1)	Each bay	(1)	Anchor cable required.

1 Any length.

f. Construction party.—An officer or noncommissioned officer is in charge of the construction. The footbridge can be constructed in short lengths and in still water with a detail as small as 1 officer or noncommissioned officer and 10 men, and in a current, with 1 officer or noncommissioned officer and 15 men. Rapid and effective construction of the footbridge requires a detail of about 4 to 6 squads, depending upon the width and velocity of the stream, assuming that all parts of the equipment are piled convenient to the bridge site.

g. Bridge site requirements.—(1) The *technical requirements* for a good footbridge site are—

FIGURE 45.—Assault boat used to carry anchor cable across stream.

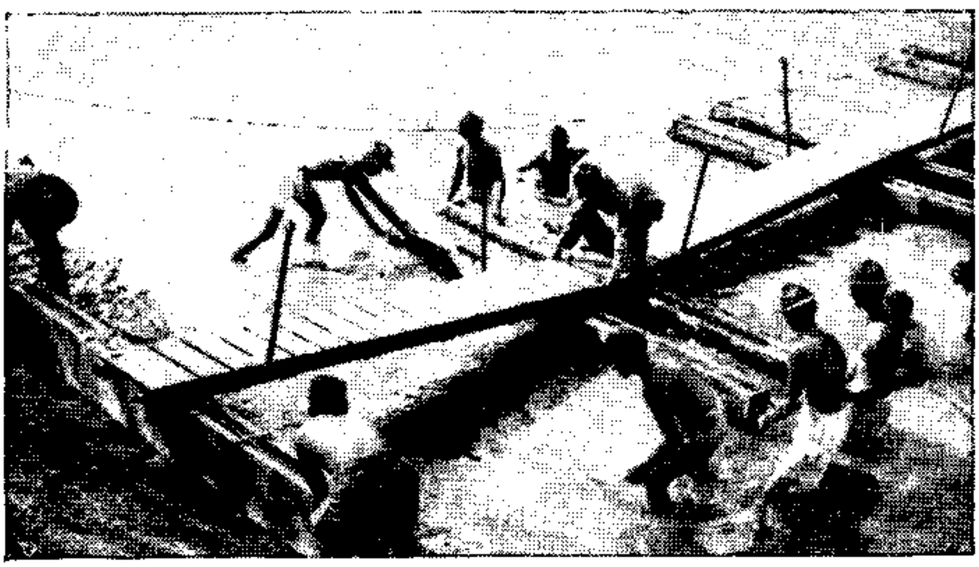

FIGURE 46.—Construction of footbridge by successive bays.

(*a*) Proximity to a road, path, fence line, or other feature on the near shore that will guide troops carrying the equipment to the site, as well as those who are to cross the bridge.

(*b*) A cleared area on the near shore, either flat or with an even gentle slope, large enough for the assembly of the bays and the convenient piling of the bridge parts in the vicinity, and close to the water's edge.

(*c*) Depth of water close to the near shore not over a man's waist, to facilitate connection of assembled bays to the completed portion of the bridge.

(*d*) Absence on both banks, and especially on the near bank, of high bluffs, or other obstructions to the construction operation or the passage of troops onto or off the bridge.

(*e*) Trees or other existing holdfasts (figs. 43 and 44), to which anchor and float cables and guy lines may be attached without having to prepare holdfasts.

(2) The *tactical requirements* for a good footbridge site are—

(*a*) Proximity to crossing points most suitable to scheme of maneuver.

(*b*) Proximity to roads, paths, fence lines, or other features on the far shore that will facilitate reorganization, control, and direction of troops after crossing.

(*c*) Concealment from enemy ground and air observation.

h. Selection of site.—The bridge site and the routes to it are selected by reconnaissance and a consideration of the technical and tactical requirements. During the reconnaissance the width and current of the stream are measured or estimated and a decision made as to whether the anchor and float cables must be used or the guy lines alone will suffice.

i. Preparations.—The equipment is delivered by trucks to a previously selected point affording defilade from both observation and fire. Here the engineer construction detachment and the footbridge equipment normally have rendezvous with the Infantry which is to furnish carrying parties and to cross on the bridge. This forward assembly area should be sufficiently near the stream to avoid long and exhausting carrying operations, yet must be far enough away to eliminate chances of discovery by the enemy. The equipment is brought to a shore assembly point near the water's edge where the assembly of bays of the bridge takes place. Noise, confusion, congestion, delay, and the arrival of parts of the equipment at the bridge site out of proper order must be avoided. The training of all troops for foot-bridge construction must include this phase of the work, which, in maneuvers or actual operations, should be rehearsed jointly by the engineers and the Infantry concerned.

j. Construction procedure.—(1) The officer or noncommissioned officer in charge of construction designates the point where the floats of the individual bays enter the water, the point of landing on the far bank, whether anchor and float cable or guy lines alone are required, and gives the command to begin construction.

(2) An assault boat or other suitable boat, with the anchor cable on its reel, blocks and tackle, pickets, lashings, and other needed accessories, is carried forward to a point upstream from the bridge near where the near shore anchor cable connection is to be made. Using the boat and equipment, a detail carries the anchor cable across the stream (fig. 45).

(3) Sections are organized for shore assembly of the parts, for handling of the bridle lines, the cables, guy and handrail lines, and for carrying material to the site. Cables, ropes, accessories, and tools should be the first articles delivered, followed by duckboards, floats, and handrail posts.

k. Night construction.—In general, construction procedure at night is the same as in daylight, but is even more dependent upon careful planning, close control, and adequate training. The chief difficulty occurs in the proper placing and handling of the cables and lines and in the directing of the bridge to the proper point on the far shore. These difficulties will vary widely with the stream, the force of the current, and the degree of darkness, but may be minimized by reconnoitering the site and laying plans carefully in advance. Except when the stream is very narrow, or there is moonlight, the anchor cable should be used habitually, even though not otherwise necessary, because by this means the direction and alinement of the bridge can be much more readily maintained. A single flashlight covered with blue cloth can be used on the far bank to indicate the point of landing for the anchor cable of the bridge and later the point of landing of the bridge, with virtually no danger of detection by the enemy. The use of other shielded flashlights may be permissible for signalling or for controlling the cables and lines, but the use of flashlights to aid in the assembly of the bridge itself should not be necessary. Luminous markers or paints, white tracing tape or white pieces of cloth are most useful to mark essential features such as the assembly templet and avenues of approach.

l. Construction time.—The time required for construction is affected by conditions obtaining at the bridge site, such as the current, character of banks, amount of unrestricted space available to work in and its proximity to the water's edge, weather, and the condition and state of training of the men. Trained troops have built about 350 feet of footbridge in a 3-mile current in as little as 8½ minutes of daylight, and 18 minutes at night without the use of any lights. A shore assembly detail has assembled a completed bay on land in 8 seconds. Assuming service conditions, a fairly good bridge site, and troops somewhat fatigued but with some experience and training with the equipment, the table following gives reasonable basic averages from which time estimates may be made. These figures must be increased or decreased according to conditions. Under peacetime drill conditions, the rates of progress given in the table should be doubled by troops who have reached a satisfactory state of training with the equipment.

TABLE XXIX.—*Number of 12-foot bays constructed per minute*

Current (miles per hour)	Day	Night
Less than 2	2	1
2 to 3	1½	¾
Over 3	1	½

m. Uses of footbridge.—The bridge will carry men, their equipment, and infantry-accompanying weapons. The men should cross at a run at a distance of 2 or more paces. In a stream with considerable current, it is possible to cause the bridge to overturn by too much overloading. An infantry rifle company can cross a stream of moderate width in about 3 minutes during daylight or in 10 minutes at night. A battalion will require about 10 and 35 minutes, respectively, under the same conditions. If at any time congestion occurs so that four or five men are jammed together on one 12-foot section, the bridge will submerge slightly, but will not overturn, providing the current is slight. The rate of crossing is limited more by the boldness of the troops crossing than by the capacity of the bridge itself. The officer in charge of the bridge supervises the movement of troops across, and stations one of his men at the far end to aid in clearing the troops. If the bridge is to remain in place for some time after it is completed, a suitable guard is left to adjust cables and lines, maintain it in proper condition, and control its use by the crossing troops. Priority of traffic on the bridge in both directions is governed by the orders of the local or higher commander for the conduct of the crossing. In the absence of such orders, this feature is handled by the engineer officer or soldiers in charge of the bridge.

n. Dismantling.—For dismantling the bridge, working details of about the same size as for construction are required. In general, the process is merely the reverse of that procedure. As the float cable is primarily a safety measure when the bridge is loaded, it can be taken in at once except under the most extreme conditions. It will be advantageous in the case of a long bridge in a current to have the anchor cable and bridle line details or the guy line detail, as the case may be, change the alinement of the bridge slightly by adjustment of the lines so as to give it a slight downstream slant toward the near shore so that the force of the current can be used to assist in pulling in the bridge.

o. Wide bridge.—This bridge will seldom be used, since it requires three times as much material as a footbridge of the same length. The most probable utilization of this type of bridge will be to provide a larger capacity bridge over narrow streams of 100 feet or less width. It is unlikely that it will be built in lengths exceeding 200 feet because of the quantity of material required. Although the bridge offers more resistance to the current than the footbridge, it also has much more rigidity and stability, particularly laterally, than the footbridge. Because of this the float cable will not be required. However, because the wide bridge is much more difficult to push out across the stream and to hold in place because of its greater resistance to the current, the use of the anchor cable with the wide bridge will be habitual, except for short bridges in still water. The general methods of construction, the preparations, and the construction procedure for this bridge are virtually identical with those for the footbridge. The dismantling procedure also is the same. Each assembly carrying detail must be increased to 1 noncommissioned officer and 12 men, and the material carrying details must be correspondingly augmented. With at least 2 shore assembly details working, the bridge can be constructed in about twice the time that would be required for a footbridge of the same length under the same circumstances. The wide bridge will carry—

(1) Foot troops in column of threes at a walk at the rate of 100 men per minute.

(2) Foot troops in column of twos at a run, at the rate of 150 men per minute.

(3) Solo motorcycles or motorcycles with side cars at speeds not to exceed 10 miles per hour.

(4) Light vehicles not exceeding 2,500 pounds in weight.

■ 86. KAPOK FOOTBRIDGE.—*a. General.*—This equipment, now obsolescent, has an obvious advantage over the 1935 model in that it is easy to assemble under cover, in rear of the shore line, and to carry forward without detection by the enemy. For this reason it is of definite value as an assault bridge. Repairs to it can be made easily and quickly with the tools and personnel available in an engineer combat company. An outstanding disadvantage is that it tends to capsize in strong currents.

b. Description of unit.—The bridge itself is a floating footbridge, the buoyant supports of which are wooden crates containing kapok pillows. (See fig. 47.) *A unit of this bridge* consists of twenty-two 12-foot sections fastened together at the ends, making a total length of bridge of 264 feet. Each section is a complete raft, approximately 12 feet long, 3 feet wide, and 6 inches deep. It is provided with three rope handles on each side for carrying purposes, two handrail post sockets located amidships on the outer edge of the section, and four end-fastening devices. The walkway consists of the tops of the rafts and no additional flooring is necessary. Raft clips are provided to prevent vertical end displacement between successive sections. Each section has approximately 180 pounds displacement for each inch of draft. A section used as a raft can transport three men safely. The assembled bridge is capable of passing a column of infantry soldiers in single file with full field equipment. One complete unit of bridge (264 ft.) can be transported in two 1½-ton trucks.

c. Serviceability.—Immediate destruction of the unit by machine-gun and rifle fire is almost impossible. With all pillows punctured, the section will still stand up for approximately 2 hours without becoming waterlogged, and even with one or more sections completely waterlogged the buoyancy of the bridge as a whole will render it still able to transport troops. Only a direct hit from artillery or from air bombardment will destroy its effectiveness.

■ 87. PONTON BRIDGE, 7½-TON, MODEL 1926.—*a. Capacity.*—The maximum safe load for this bridge, when normally constructed, is 7½ tons per bay, with a maximum single axle load of 6 tons and at least 9 feet between axles. This permits the accommodation of all loads not over 7½ tons that should normally accompany an infantry or cavalry division. In an emergency the bridge may be used to pass the 10½-ton tank or other 10-ton vehicles, but these are considered unsafe loads under normal service conditions. If loads in excess of 7½ tons must be carried, the bridge may be reinforced by adding extra balk and chess, and by placing extra boats in the spans. When thus reinforced, the bridge will carry 15 tons, for which load the trestle was designed. The reinforced bridge of this type has 7 balk, one extra boat in each floating span, and two extra in the hinge sill raft, with 13 balk in the trestle and abutment span.

b. Equipment.—(1) The ponton has a duralumin frame and an aluminum skin riveted to the framework. It is 26½ feet long, displaces 12,500 pounds with a 9-inch free-

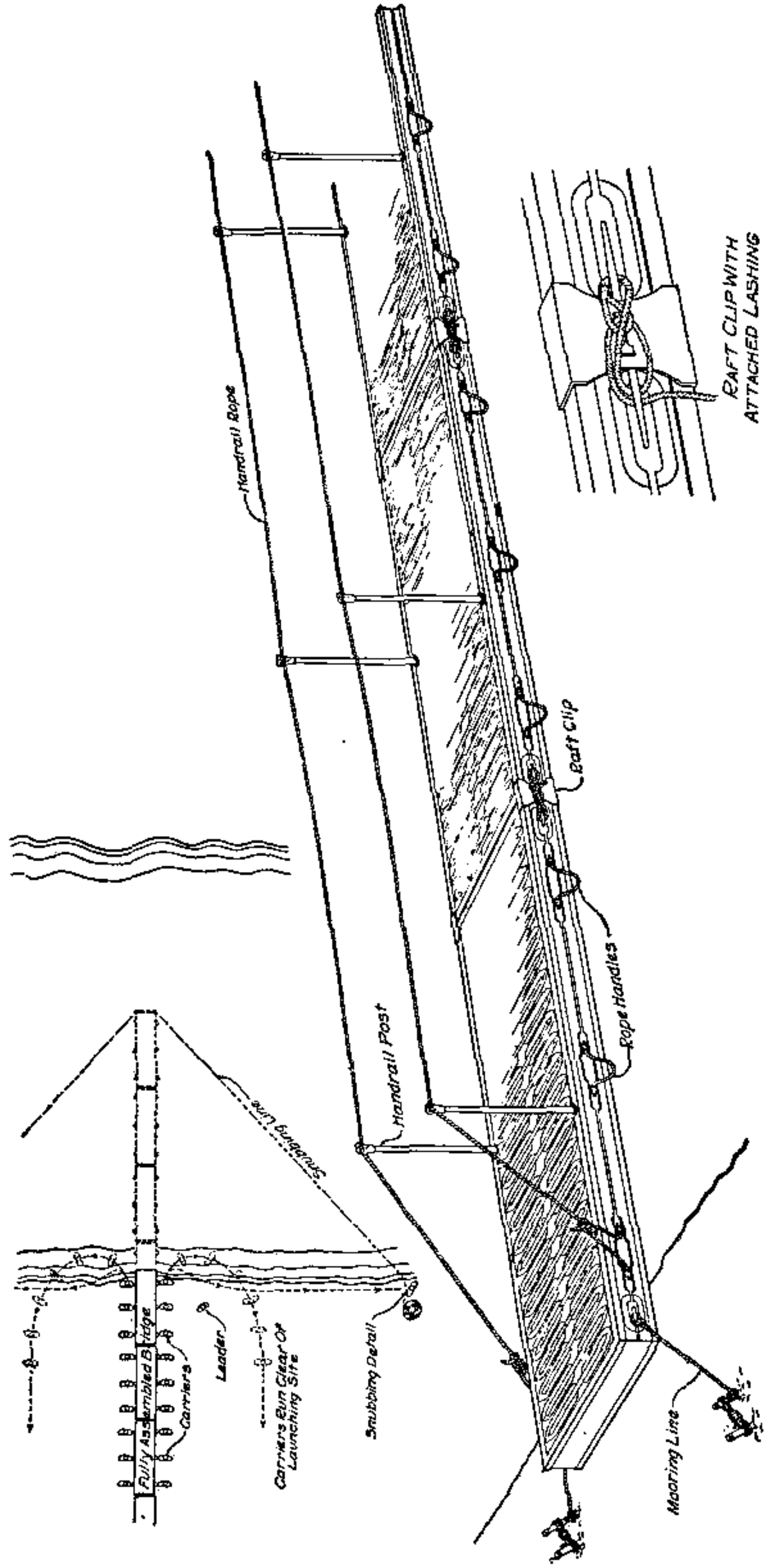

FIGURE 47.—Kapok footbridge.

board, and weighs about 1,400 pounds. To hold the balk down tightly on each side, 14 metal balk fasteners, with 2 extra spares, are mounted on a 2-inch steel tube. The ratchet type balk fastener works on the cam principle. It is hooked into the eyes on the balk and tightened by pushing down on the handle, which is locked by the pawl. It is more positive and rapid than the rope lashing, which is often stretched or loosened. Four turnbuckle fasteners are provided as spares to secure extra balk, or to be used in case of breakages.

(2) The trestle is of the same type as the heavy trestle, Model 1924, except that the box girder and posts are made of aluminum alloys. The weight is about 650 pounds. It will safely carry 15 tons.

(3) The balk are 4 inches by 6 inches by 21 feet 5 inches, except trestle balk, which are 16 feet 3½ inches long; these weigh 140 and 100 pounds, respectively. Seven balk are placed under the roadway and two are used for siderails in all spans, including the abutment, trestle, and hinge spans. Siderails are clamped or lashed to the outer balk. The siderail clamp operates like a carpenter's C-clamp or bench vice clamp and has the same advantages that the metal balk fastener has over the rope lashing.

(4) The chess are of white pine 2⅛ inches by 11¾ inches by 12 feet, weighing 60 to 80 pounds, and are notched at the ends.

(5) The abutment and hinge sills are exactly alike and are of wood 5¾ inches by 7¾ inches by 12 feet.

(6) Outboard motors and light accompanying boats are available for use with this equipment.

c. Transportation.—A complete unit of the light ponton bridge (250 feet long) can be carried on 33 truck-drawn trailers. Of these, 12 are for pontons, 2 for trestles, 6 for abutments, 12 for balk and chess for floating spans (1 as spare), and 1 for spare trestle balk.

d. Unloading the equipage.—The boats of the 7½-ton equipage being carried, right side up, on two-wheel trailers, the easiest method of unloading them is to slide them off the rear end. A detail of 1 noncommissioned officer and 16 men is desirable, although it can be done by less in case of necessity. Special care should be taken to avoid damaging the aluminum skin of these pontons by dragging them over or dropping them on sharp rocks or stumps. The location of the bridge having been selected, the ponton carrying vehicles are brought as near the river bank as possible, with the rear ends of the trailers toward the stream. The pontons are released and slid from their beds directly into the water whenever possible. When a ponton cannot be unloaded directly into the water, one end is slid to the ground and the ponton then let carefully down by its unloading detachment. A barrel or roller is helpful in this operation. The ponton is then dragged or carried to the water and launched. Where the banks are too high to permit of launching the pontons directly into the water, the boats can be skidded into the water on balks laid from the bank. As soon as the pontons are in the water, the anchors are brought aboard, and cables attached and coiled in the bows of the pontons, with the anchor on top with its flukes projecting over the gunwale. The trestles and other material are unloaded in convenient places near the work, their location depending upon the method of construction to be employed. After pontons and trestles have been removed, the trailers should be spotted so the balk and chess may be unloaded and piled near the abutment in two separate piles on each side, and just clear, of the approach. In some cases it may be feasible to leave this matériel on the trailers and remove it when needed in the bridge to save one extra handling. The abutment, trestle, and hinge-sill-raft material should be unloaded on the shore at points near where it will be used. In slow streams all pontons are moved downstream from the abutment except those which will cast upstream anchors. In swift streams all pontons are moored well upstream from the abutment.

e. Preparation of abutment.—The abutment is prepared by excavating on each bank a trench 14 feet long by 1 foot deep by 1 foot wide to receive the abutment sills. These should be horizontal, exactly perpendicular to the axis proposed for the bridge, and firmly secured in place by backfilling with earth and by pickets. In some cases footings may be required.

f. Abutment and trestle spans.—The standard and improvised types of floating bridges may or may not use a trestle, depending on whether or not the water at a distance of one span from the abutment sill is of sufficient depth to float a loaded ponton. Where more than one trestle is used at one end of the bridge the spans between trestles are called *trestle spans*. In the construction of the abutment span, when a trestle is to be used, two cases may arise: first, when the water at a distance of one span from the abutment sill is not deep enough to float a ponton; and second, when the water is of sufficient depth to float a ponton or raft loaded with a trestle. In the first case, the trestle is assembled on cribbing at approximately the distance of one span from the abutment sill, and is raised to a vertical position; the transom is shifted on the cribbing to its position, the columns or legs of the trestle are lowered, and the transom is raised to its required height. The trestle pins are then inserted and the cribbing is removed. The location of the abutment sill is then determined by measuring shoreward with two trestle balk placed upon the transom. In the second case, trestles are assembled on a 2-boat raft, two balk of which are laid so as to project shoreward over the shore ponton. The trestle is assembled with its transom resting on these two projecting balk. The raft is moored over the site and the trestle is centered, raised on the shore side of the raft, and spaced at the proper distance from the abutment sill by the use of two trestle balk (fig. 48). The remainder of the erection is as described above.

g. Methods of construction.—(1) *General.*—The methods of constructing the bridge are by successive pontons, by parts, and by conversion. In all cases care must be taken to provide a free hinging motion between the fixed and floating pontons of the bridge to allow for the rise and fall in the elevation of the water due to tides, floods, and wave action. The new equipage is provided with a special hinge sill (see fig. 53) placed between the first and second boats and suspended by special hinge hangers from each balk of the first boat span. The balk from the trestle transom rest on this hinge sill and thus provide the necessary hinging action.

(2) *Construction by successive pontons* (fig. 49).—When the abutment span or the abutment and trestle spans have

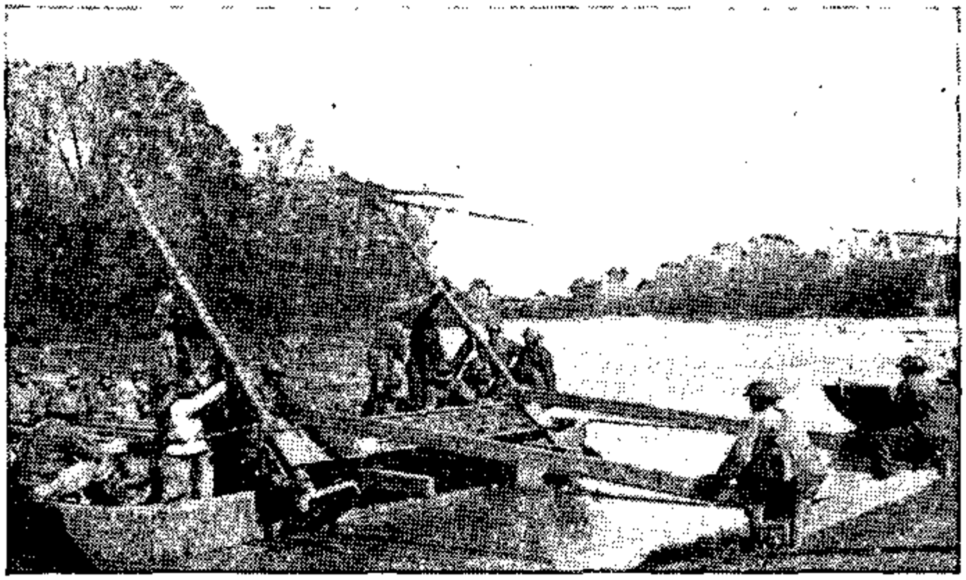

FIGURE 48.—Hinge sill raft being used for placing trestle.

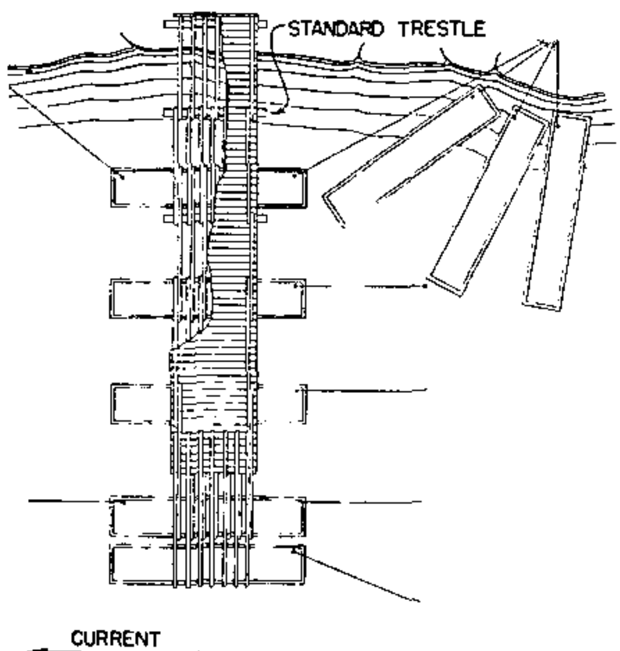

FIGURE 49.—Method of construction by successive pontons.

been constructed, a ponton is brought close to the end of the span just completed. The free ends of the cables, previously fastened on the bank 30 or more paces above and below the abutment sill, are passed onto the ponton. The ponton then is pushed off with a set of balk until the inner ends of the balk can be placed on the hinge sill, when all fastenings are completed. The floor is then laid on the balks placed and the second ponton is brought alongside the first, its anchor having been previously cast. A second set of balk is brought up and the operation is repeated until the other shore is reached, where an abutment sill is laid as before described, and the shore bay completed. Unless the supports are manageable boats, all anchors should be dropped from special boats and the cables passed onto the pontons.

(3) *Construction by parts* (fig. 50).—For long bridges the method by successive pontons requires materials to be

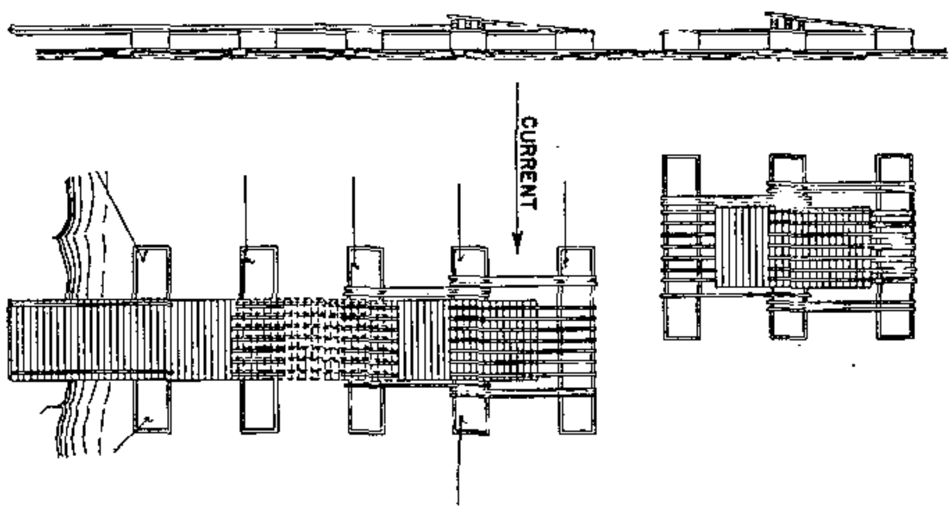

FIGURE 50.—Method of constructing bridge by parts. (First bay may be a trestle bay instead of as shown.)

transported considerable distances. These may be reduced by constructing the bridge in parts along the shore above the site of the bridge. Each part may conveniently consist of three bays. To construct the parts, a ponton is moored close to the shore and gangways are temporarily laid to it from the bank. Two other pontons are brought up outside the first, and two bays are constructed successively as described in the method by successive pontons, except that the outer bay is constructed first and shoved into the stream by balk of the inner bay. Enough of the floor is omitted from each end of the part to permit fastenings to be made. Materials for the floor of one bay are loaded on the part thus formed, which is then pushed off and conducted to the line of upstream anchors where the anchors are cast and the part is dropped down into its place in the bridge.

(4) *Construction by conversion* (fig. 51).—The bridge is constructed parallel to the shore and upstream from the bridge site selected. Siderails are fastened on all except the end bays. Material is placed on the upstream end of the bridge to make the connection with the far shore when the bridge is in its final position. The bridge is then allowed to float down until the downstream ponton is within 15 yards of the near abutment and is made fast to the shore. The material for the near abutment and bay is brought down in a ponton. The upstream end of the bridge is then shoved off and the bridge pivoted on its downstream end which is not permitted to ground. The progress of the bridge is checked just above the line of abutments, and it is slowly shoved into its final position. The downstream anchors are cast from separate pontons as in the construction of bridge by parts. The far abutment is then constructed and the shore bays are laid.

(5) *Comparison of the methods.*—The method of construction by successive pontons possesses an advantage over the others by being applicable to all streams regardless of velocity and by requiring the minimum quantity of equipage and the fewest pontoniers. However, the labor of constructing a bridge by this method increases rapidly with the number of bays. The method by parts is ordinarily used in connection with the method of successive pontons. When a bridge is to be more than 40 bays in length, these methods are combined as follows: The bridge is begun at both ends, if possible, by successive pontons and is pushed out rapidly toward the middle of the stream. The two portions thus formed are connected by parts which are constructed in the meantime along the river bank above the bridge. The construction by conversion is the most difficult of these three methods. To insure success, the current must be moderate, the holding ground good, and the pontoniers

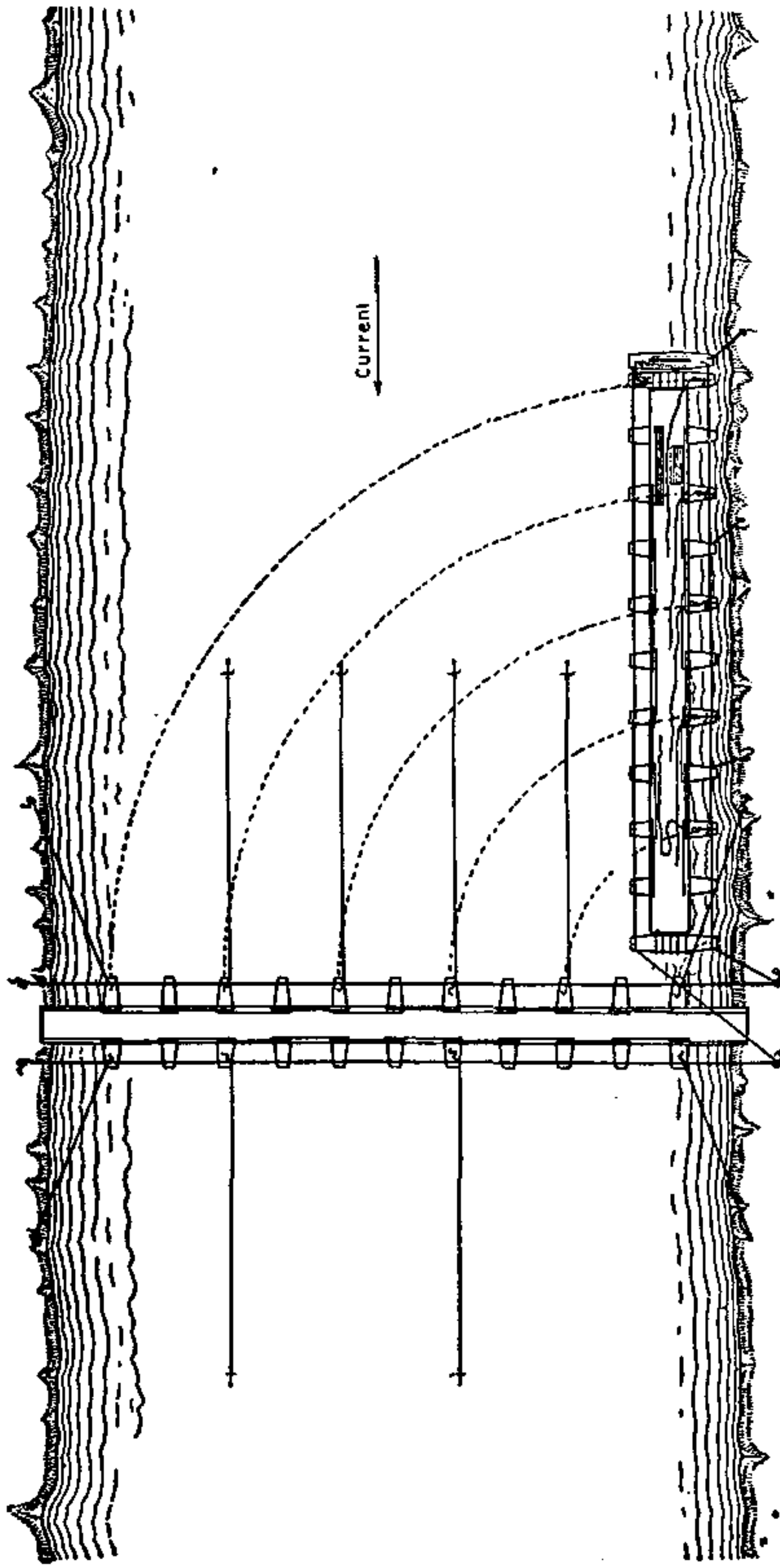

FIGURE 51.—Method of construction by conversion.

highly trained. The awkwardness of a single man, the dragging of an anchor, or the parting of a cable may cause the failure of an entire operation. The opportunity of employing this method successfully will be exceedingly rare. A fourth method, namely, construction by rafts, is applicable only to the model 1869, heavy equipage, but an adaptation of it is used to create draw spans in floating bridges, as will be explained later.

■ 88. PONTON BRIDGE, 10-TON, MODEL 1938.—*a. General.*— The individual pontons for this bridge are of aluminum construction, 28 feet long, 5½ feet wide, and 2 feet 8 inches deep. They weigh 1,450 pounds each, and have a maximum displacement of 22,800 pounds. It is thus seen that they are 1½ feet longer, 6 inches wider, 2 inches deeper, and 250 pounds heavier than the 7½-ton pontons and that their buoyancy is 4,300 pounds greater. The design of the 10-ton ponton, both generally and in detail, is practically identical with the latest type 7½-ton ponton, except for a few changes in the material and in other respects necessitated by the larger dimensions involved. Modifications are, of course, required for the trailer, the trestle, and balk fittings. Since the boat width is increased by 6 inches and the balk are unchanged in length, each span (center to center of boats) is reduced from 16 to 15½ feet. This means that for any given length of bridge more boats will be required than in the case of the 7½-ton bridge. Eight balk, instead of seven, are used in each span of the bridge.

b. Construction of the bridge.—The 10-ton ponton bridge is constructed by the same methods as the 7½-ton bridge. Transportation, methods of unloading the equipment, preparation of abutments, and erection of the trestle and hinge spans are all similar to that which has been described.

■ 89. PONTON BRIDGE, 23-TON, MODEL 1924.—*a. General.*— This bridge (fig. 52) possesses sufficient buoyancy, strength, and width of roadway to provide safe passage for one lane of traffic consisting of all transportation with an army in the field. No limitations are made as to the spacing of vehicles in the stream of traffic crossing the bridge with the exception of loads of over 20 tons. While on the floating portion of

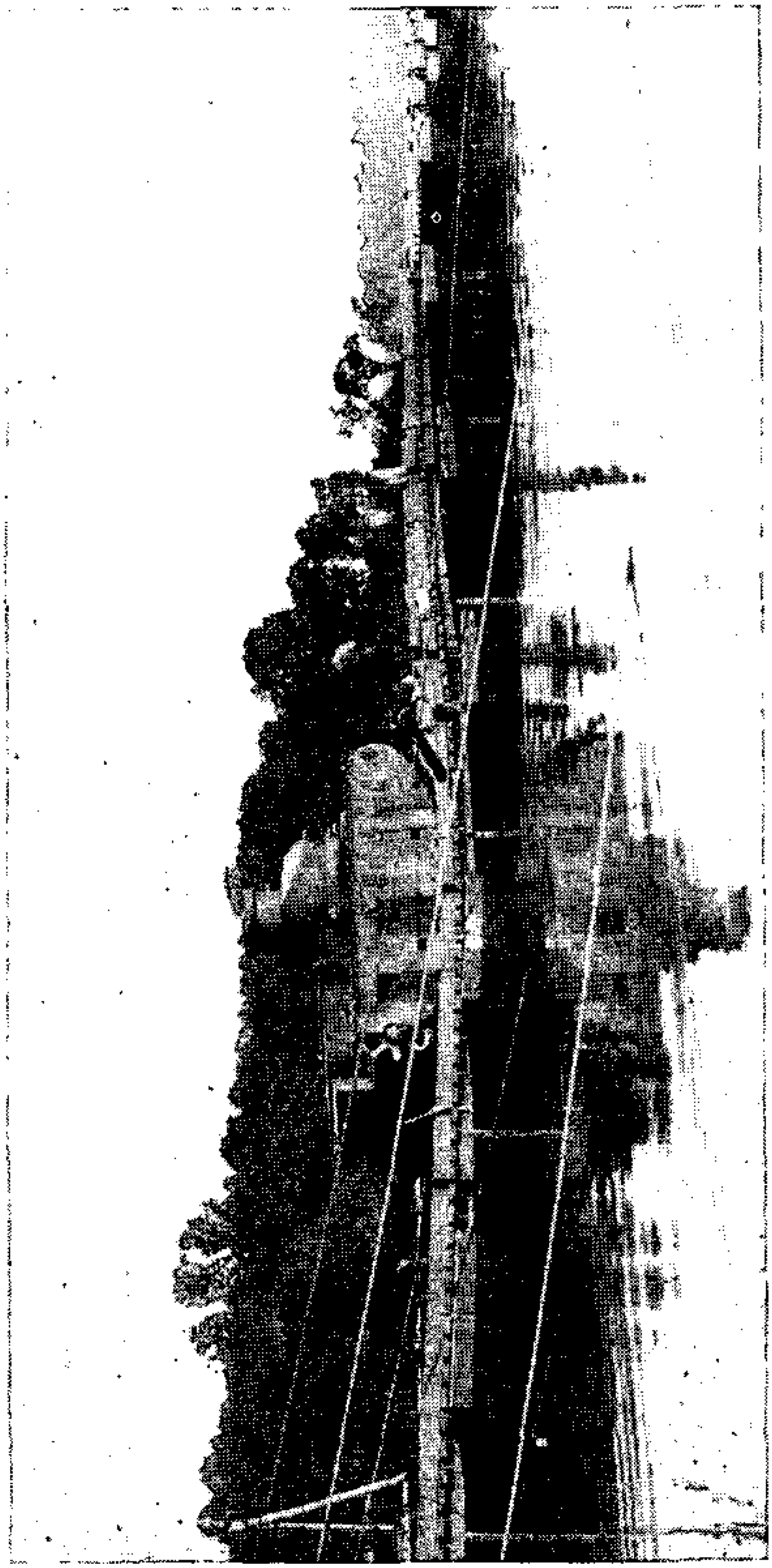

FIGURE 52.—Behavior of 23-ton bridge (model 1924) under 23-ton load.

the bridge, intervals of over 32 feet should be maintained between loads of over 20 tons. By increasing the number of pontons and otherwise reinforcing it, the bridge can be made to carry approximately twice the load for which it was designed. Each unit, normally carried by a platoon, is sufficient for about 250 linear feet of bridge. All spans are 16 feet center to center of boats, except the two from the end pontons to the trestles. These spans are less than 16 feet, due to the provision of a hinge made by carrying the outer end of the trestle balk on a hinge sill suspended transversely between the first and second boats, instead of directly on the first boat. (See fig. 53.)

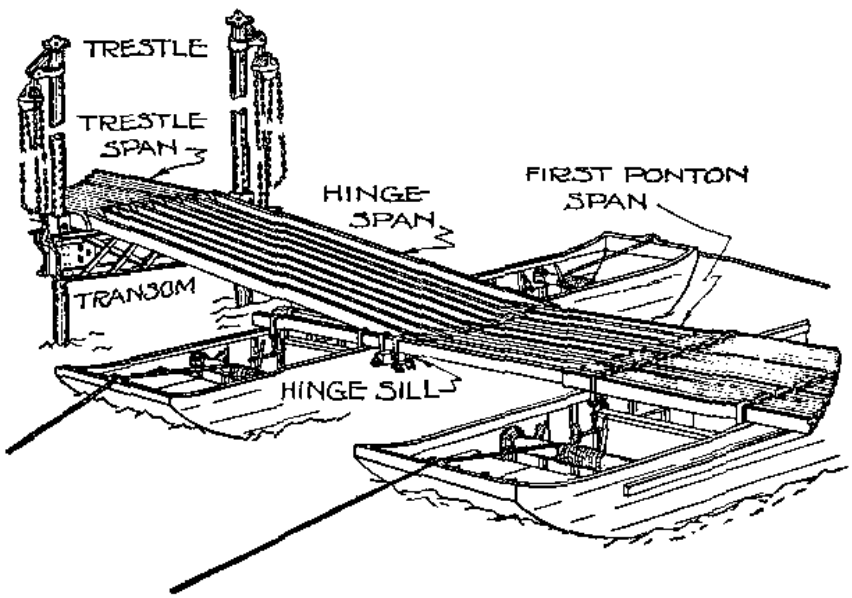

FIGURE 53.—Hinge sill raft and trestle (23-ton model 1924 bridge).

b. Equipment.—(1) The ponton is 32 feet long, 6 feet 6 inches wide, side almost straight, 3 feet 3 inches deep amidships, and 3 feet 9 inches deep bow and stern. The weight is approximately 4,000 pounds. The frame is of Douglas fir, and the planking is of white pine. The displacement is 26,100 pounds with a 10-inch freeboard. It will ferry an infantry platoon (57 men and 1 officer) plus a crew of 9 (or crew of 2 with outboard motor) with an 18-inch freeboard.

(2) The trestle consists of a steel latticed girder transom,

columns of cold drawn steel tubing, steel shoes, and chain hoists ($1\frac{1}{2}$-ton capacity) for adjusting the transom on the columns. The load is carried on steel pins through the columns. The trestle will safely carry 25 tons. The weight *complete* is 1,690 pounds. (During tests the Mk. VIII tank, weighing 43 tons, was crossed over the trestle.) A light duralumin trestle, weighing 1,200 pounds without chain hoists, has been designed.

(3) The balk are fir, 23 feet by $5\frac{3}{16}$ inches by $7\frac{3}{4}$ inches. Trestle balk are of the same cross-section, but only 16 feet $3\frac{1}{2}$ inches long. Rigid metal balk fasteners are used to secure balk to the boats.

(4) The chess are pine, $2\frac{7}{8}$ inches by $11\frac{3}{4}$ inches by 13 feet 6 inches.

(5) The sills are of wood, 6 inches by 9 inches by 13 feet 6 inches, equipped with metal fittings at each end to facilitate handling, and weigh approximately 170 pounds. The two abutment sills and the two hinge sills are all identical.

(6) The floor system will carry the heaviest Army load with a factor of safety in excess of two. Nine road balk are placed 18 inches center to center, and two balk are used for siderails. A transverse balk, 13 feet 6 inches by $5\frac{1}{2}$ inches by 10 inches, is placed under the center of each span to carry a portion of the load to the siderails and aid in the distribution of the load. Weight of the transverse balk is about 175 pounds.

c. *Transportation.*—The heavy equipment is entirely motorized. The equipment of one platoon is carried on 17 trailers, each drawn by a truck. Headquarters and service company carries a small reserve of balk and chess. As actually carried at present, it is transported on trucks and trailers, the chess and miscellaneous items being carried on the trucks. The trailers are of the following capacities:

Total *truck-drawn*	12 ponton trailers.
	4 trestle trailers.
	1 spare balk trailer.
Total	17 trailers.
Each ponton trailer	1 ponton and 11 balk.
Each trestle trailer	1 trestle and 18 balk.

d. Unloading the equipage.—The pontons are too heavy to be lifted and carried about by hand. Rollers are provided on the trailers to assist in lowering the boats to the ground and for their movement on balk tracks when off their trailers. Individual items of equipment are spotted along the shore or in vicinity of the site as in the case of the light ponton equipage.

e. Construction of the bridge.—Figure 53 shows details of erection of the trestle, and construction of the hinge span. The rest of construction proceeds as for the light ponton bridge, with alternate methods possible.

■ 90. SUMMARY AND DATA.—Tables XXX and XXXI indicate the characteristics, safe loads, and personnel and time required for the erection of various type bridges. It will be noted that, in addition to the bridges previously described, mention is made of heavy ponton equipage, model 1869, and light ponton equipage, model 1869. These bridges have been outmoded by the newer equipment, but are still available in depots and might be used for training purposes. The old heavy trestles are adaptable to dry crossings and for bridges in shallow streams; if so used, it is necessary to use adequate longitudinal bracing.

TABLE XXX.—*Characteristics of standard ponton bridges*

	Heavy ponton battalion, model 1924	Light ponton company, model 1926
Length of bridge per bridge platoon	250 feet.[1]	250 feet.[1]
Spans (center to center—approx.):		
a. Abutment to trestle	16 feet.	15 feet.
b. Trestle to trestle	16 feet[1].	15 feet.[1]
c. Trestle to hinge (maximum)	16 feet.	15 feet.
d. Effective length of hinge sill raft.	4 to 12 feet[2].	4 to 12 feet.[2]
e. Ponton to ponton	16 feet.	16 feet.

[1] Four trestles are used in this bridge in normal construction. Using all basic quantities, the lengths given can be built. Unless all trestles can be used, the length of single bridge that can be built by several platoons of equipage end to end is considerably less than 250 feet times the number of units employed.

In this case the exact length of bridge that can be built must be computed, using only the number of spans which can be actually employed.

[2] The effective length of the hinge sill raft may vary from 4 to 12 feet, depending on location of the hinge.

TABLE XXX.—*Characteristics of standard ponton bridges*—Continued

	Heavy ponton battalion, model 1924	Light ponton company, model 1926
Number of boats:		
a. Per bridge platoon	12	12.
b. Total per bridge company	24	48.
c. Total per battalion	48	—
Number of trestles per bridge platoon	4	4.
Width of roadway (clear)	11 feet 3 inches	10 feet.
Dimensions of balk:		
a. Boat balk	5 3/16 inches by 7 3/4 inches by 23 feet.	4 inches by 6 inches by 21 feet 5 inches.
b. Trestle balk	5 3/16 inches by 7 3/4 inches by 16 feet 4 1/2 inches.	4 inches by 6 inches by 16 feet 3 1/2 inches.
Weight of one balk:		
a. Boat	235 pounds	140 pounds.
b. Trestle	165 pounds	100 pounds.
Number of balk under roadway per span, normal construction.	9	7.
Dimensions of chess	2 7/8 inches by 11 3/4 inches by 13 feet 6 inches.	2 1/8 inches by 11 3/4 inches by 12 feet.
Weight of one chess	95 pounds	75 pounds.
Ferrying capacity per boat, Infantry, exclusive of crew.	58	25.
Number men in boat crew	7 to 9	5 to 7.
Safe buoyancy of ponton [3]	22,000 pounds	10,400 pounds.

[3] The safe buoyancy given is the approximate net safe buoyancy of the boat in the bridge, that is, the displacement of the ponton with a safe freeboard (approx. 9 in.) minus the weight of one span of flooring. The weights of one span of flooring of the 23-ton bridge, model 1924, and the 7½-ton bridge, model 1926, are approximately 4.100 and 2,100 pounds, respectively.

TABLE XXXI.—*Personnel required and time of construction for ponton bridges* [1]

Type of bridge	Number of men used	Time of construction
Canvas bridge, model 1869	86	2 to 4 hours.
Heavy bridge, model 1869	86	2 to 4½ hours.
Light bridge, model 1926 or 1938	102	2 to 4½ hours.
Heavy bridge, model 1924	145	2½ to 6½ hours.

[1] The data in this table are based on the erection of a normal span bridge of the length carried by one bridge platoon. Exact information on the personnel required and the time of construction for reinforced bridges is not available, as these items vary greatly with local conditions and the method of reinforcement used—from 25 to 100 percent of those given in the table.

■ 91. DRAW SPANS IN FLOATING BRIDGES (fig. 54).—In navigable streams it is frequently necessary to provide a draw span in floating bridges to permit the passage of river traffic. This is effected by introducing one or more rafts as previously described, over the channel of navigation. One end of a swing line is attached to the bow of the middle ponton of the draw and the other end to the stern of the second ponton from the opening on the side toward which the raft is to be swung. To open the draw the raft is disconnected from the adjacent pontons and allowed to drop downstream from the bridge by paying out the cable of its upstream anchor. When the swing line becomes taut, the raft will swing into the required place as the anchor cable is further slackened. The raft is then made fast by the swing line. It is replaced in the bridge by casting off the swing line and hauling in the cable of the upstream anchor. The draw may also be formed of two rafts, one dropping to the right and the other to the left of the opening. Draw spans may be made in all bridges by taking up the flooring and disconnecting the balk.

■ 92. ANCHORAGE OF FLOATING BRIDGES.—*a. General.*—The anchorage of the pontons of a floating bridge is of the greatest importance. The pontons should be so placed as to present the least obstruction to the current. In nontidal

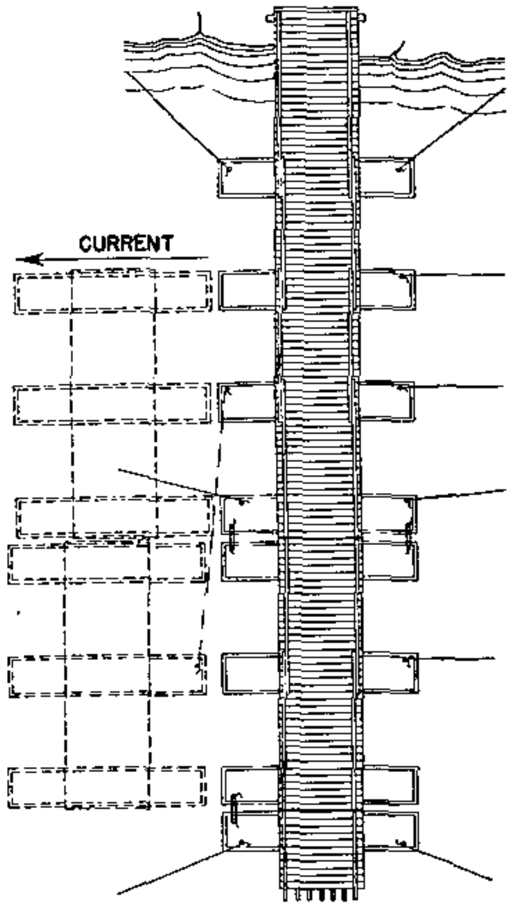

FIGURE 54.—Raft draw in floating bridge.

streams, all the bows (if the pontons are of the type having bows) are placed upstream; in tidal estuaries, they should alternate up and down stream. The pontons near the shore should be secured by strong cables to rocks, trees, or deadmen on the shore above and below. In moderate currents it will suffice to anchor alternate boats upstream and every fourth one downstream; the downstream anchors are never attached to boats which do not also have upstream anchors. In swift currents it may be necessary to anchor every boat upstream. Even in slack water every second or third boat should be anchored both up and down stream to reduce oscillation.

b. Length of cable.—The length of cable between anchor and ponton should be at least ten times the depth of the stream. Otherwise the anchor is likely to drag and a downward pull is brought on the upstream end of the ponton. The anchor must be cast as nearly as possible directly upstream from the position which the ponton is to occupy, so that the ponton in the bridge will have the same position that it would assume if riding at anchor and free of the bridge.

c. Extra anchorage.—For the 1869 models of bridge equipage the anchors provided were usually sufficient. For the new 1924, 1926, and 1938 models of heavier equipment, especially when used in the reinforced types of bridge, extra improvised means of anchorage may have to be provided in swift streams to supplement that provided by the anchors issued with the equipage, even though two per boat are furnished. Anchor cables supported on floats may be provided as for the model 1935 footbridge if other means of anchorage are not adequate. Improvised anchors may be made up of any heavy materials on hand, as railway iron, pieces of machinery, lumber cribs filled with stones, or large stones. Such anchors must be of considerable weight, as dependence is placed on their mass rather than attachment to the bottom.

■ 93. PROTECTION AND MAINTENANCE OF FLOATING BRIDGES.—*a. Bridge guards.*—A guard should always be posted at a floating bridge. Sentries are posted at each end and, if the bridge is long, at intermediate points. Sentries give the alarm whenever the bridge is in danger from any cause. Sentries regulate traffic over the bridge, see that vehicles maintain proper distances, and enforce orders as to the right-of-way of vehicles desiring to cross in opposite directions. A telephone between the ends of the bridge facilitates this operation. Sentries should be provided with orders showing the maximum load permitted on the bridge and the type of vehicles whose characteristics of load and wheel base permit them to use the bridge. Any vehicles exceeding the permissible weight should be partially unloaded or not permitted to use the bridge. These orders should also give information as to the location of the bridge, the name of the highway passing over it, and the towns which the highway connects. They should show the location of alternate crossings of the stream which may be used by vehicles of too great a weight to cross at that point.

b. Inspections.—The officer or noncommissioned officer in charge of a floating bridge must inspect the cables frequently to see that they are not chafing and that the anchors do not drag. He will cause all balk fasteners, lashings, or clamps to be tightened when they work loose, and see that boats are bailed or pumped when they leak or ship water. A suitable reserve of spare balk, floor planks, cordage, etc., should be established on shore near one end of the bridge. The bridge guard stationed at the same end should be charged with preventing the removal or use of any of this reserve material for any purpose except that of repairs to the ponton bridge.

c. Passage of columns.—Infantry in column are caused to break step, while riders of horses are made to dismount and lead their animals. Halting on any bridge is to be avoided. If it is absolutely necessary to halt on a floating bridge, concentrated loads, such as the wheels of trucks and gun carriages, should be brought to rest *between* pontons. Since the greatest strains on a bridge occur when part is empty and the rest heavily loaded, columns should be made continuous and as nearly uniform as possible. If a bridge begins to sway or oscillate considerably, the column must be halted until the swaying has ceased. In case of air attack, columns are moved quickly off the bridge and to one side of the road.

d. Rules for the protection of floating bridges.—(1) The bridge must be kept clear of drift and other floating objects, especial attention being given to the anchor cables. If the objects are not too large or too numerous, they may be passed under the bridge by men working with pike poles from the piers and roadway. Large trees may be disposed of in this way by sawing them up into logs of manageable length. Floating objects may be prevented from striking the bridge by a guard upstream or by a draw span in the bridge or by a floating boom crossing the stream obliquely. A guard, if used, is placed about 1,000 yards above the bridge. It is stationed in boats at different points across the stream and is provided with cables, grapnels, anchors, dogs, hammers, saws, etc. The business of this guard is to anchor, or tow ashore, dangerous drifting bodies.

(2) The floating boom is constructed of trees united by chains and forms a continuous barrier to surface drift. Its general direction should form an angle of about 20° with the current, giving it a length about 2¾ times the width of the river. A boom is not a reliable protection.

(3) Pontons used in ice should be protected near the water line with chafing pieces or buffers consisting of wood or bags filled with sand or hay nailed to or hung over the side and extending above and below the level of the ice. Similar protection should be provided for anchor cables.

(4) In cases where ponton bridges carry a large amount of traffic, the chess should be protected from the cutting action of wheels by way planks laid longitudinally on the bridge or by straw or other light material.

■ 94. IMPROVISED FLOATING BRIDGES.—*a. Boat bridges.*—If standard ponton equipment is not available, it may be possible to utilize ordinary boats in the construction of a floating bridge. After a reconnaissance, having as its purpose the seeking out of matériel, boats are selected which are nearly uniform in size. The largest of these are then reserved for the shore ends where impact is greatest. Large boats, thinly spaced, may also be used in swift currents as a means of reducing resistance to flow. The supporting power of boats may be computed on a basis of displacement (volume of water displaced in cubic feet × 62.5 lbs.) or it may be estimated by drawing a mental comparison between the boats available and those which are standard. Since the gunwales of an average skiff are relatively weak, balk should be supported on saddle sills blocked up from the frames of the boats. If boats differing very much in displacement are used, make the bays supported by the small boats shorter than those supported by the larger ones. Avoid placing a very large boat adjacent to a very small one. With scow-built barges, which will usually have excess of supporting power, a serviceable bridge is readily built. If the boats are large and well decked, they may be placed endwise in the bridge, separated by 20 feet or more, the intervals spanned by the bays of roadway, and the decks used for roadway on the boats themselves. With boats of different shapes and sizes, such a bridge should be attempted with great caution, and only under exceptional circumstances.

b. Barrel floats.—When barrels are available, floating supports can be made by lashing a sufficient number of them in timber frames. The supporting power of any barrel or keg can be determined by weighing it when full of water and again when empty. The difference will be the maximum supporting power. A simpler method, of course, is to multiply its volume in cubic feet by 62.5 pounds. An ordinary 50-gallon barrel has a buoyancy of about 400 pounds when completely submerged. The number of barrels required for a support is obtained by dividing the total load to be borne by the supporting power of one barrel. A margin of 20 percent should be allowed, as the float must not be completely submerged.

c. Raft floats.—Rafts of timber may be used for floats when other materials are not at hand. They are durable, if not disturbed, and secure against being sunk by hostile fire. Defects are their small and decreasing buoyancy, great weight, and bulk. The net buoyancy of each stick used may be obtained from the following formula:

$$\text{Buoyancy in pounds} = c^2 \times 0.08 \times L \times (62.5 - w)$$

where c=the circumference or girth of the log at its middle point in feet, L=the length of the log in feet, and w=the weight per cubic foot of the wood.

d. Construction of rafts (fig. 55).—The rafts are constructed in the water, if possible. Arrange the logs side by side to form a point upstream. The upstream ends should be beveled on the lower side. The logs are held together by cross timbers pinned or spiked over the tops. Where the logs are of small size, additional sticks may be placed in the intervals between the others, or two or more courses may be built up, the logs of each layer at right angles to those below. The latter method has been found advantageous in constructing rafts of bamboo.

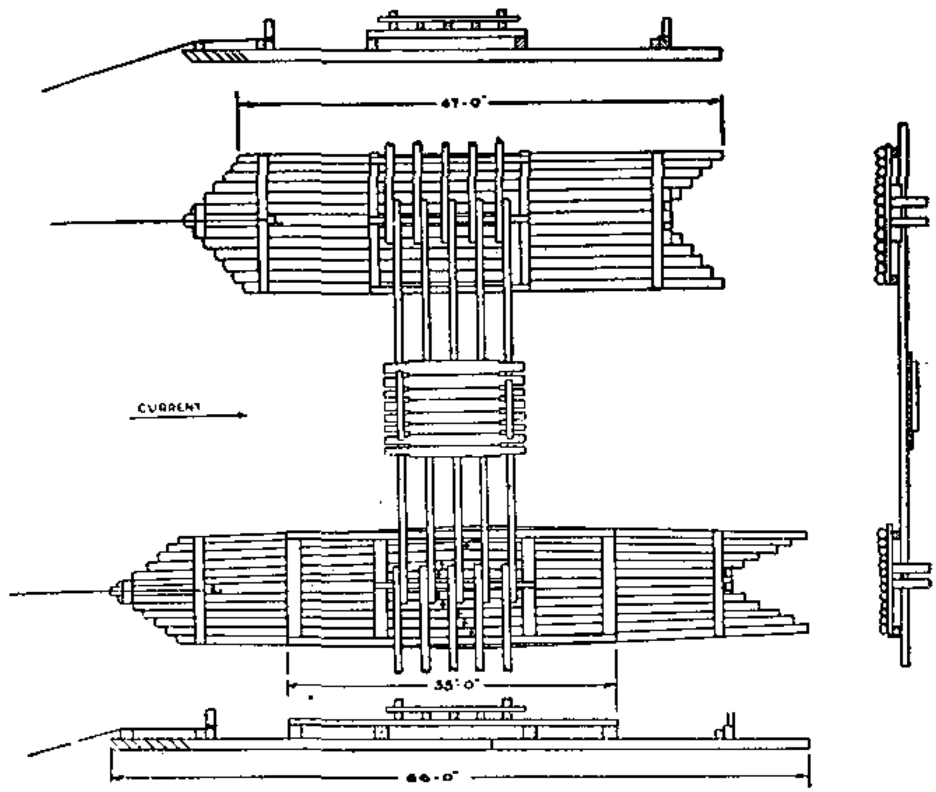

FIGURE 55.—Raft with short and long timber.

SECTION III

TRESTLE BRIDGES

■ 95. STANDARD TYPE TRESTLE BENT.—The standard type trestle is shown in figures 56 and 57. This trestle is designed to carry the heaviest loads authorized by existing regulations to accompany an army in the field and for movement by highway. The trestle shown may be used for height of posts not exceeding 16 feet. No bracing of the bent itself is required when its height is less than 8 feet. For heights over 16 feet double story trestles are used, an intermediate sill forming the sill of the upper trestle and cap of the lower, each story being sway-braced. Longitudinal cross-bracing from bent to bent is used on both sides. At times, longitudinal cross-bracing is omitted in alternate bents. Double story trestles are braced with longitudinal struts bolted to the intermediate sills, with lateral horizontal bracing on the struts from bent to bent, and with two sets of longitudinal cross-bracing.

■ 96. Description of Standard Trestle Bridge.—The standard type of timber trestle bridge now approved for stockage and issue of materials is called the "Multiple Short Span (Nonfloating) Bridge for Corps and Army Loads (H–15 Loading)." Spans should not exceed 15 feet center to center of trestles when timber stringers are used, but may be any length up to 25 feet for steel stringers. The following table shows the material used in the standard trestle bridge span.

Table XXXII.—*Material of the standard trestle bridge span*

Part	Quantity	Size
Flooring	2 layers	3 in. by 12 in. by 11 ft. planks.
Curbs		6 in. by 6 in.
Stringers	8	6 in. by 12 in. (not to exceed 16 ft. in length).
Posts	4	6 in. by 8 in. (not to exceed 16 ft. in length).
Cap and sill		6 in. by 8 in. by 12 ft.
Bracing		2 in. by 10 in.

No definite sizes of timber have been fixed for use as footings in the standard bridge. Any available material such as 2 by 6's, 2 by 8's or larger is suitable for these uses and stockage of special sizes for these purposes is considered unnecessary. The abutment sills will be 6 inches by 8 inches by 12 feet, using the same timbers as those used for caps and sills. Scabs will be of any suitable 2- by 8-inch or 3- by 8-inch materials 1½ feet long.

■ 97. STANDARD STOCKAGE.—No separate design has been made for a similar bridge for division (H–10) loads. Normally the H–15 bridge should be built, but where time and material are lacking, a bridge suitable for division (H–10) loads may be built in the same way and with the same size materials as the H–15 corps and army bridge but omitting the second layer of 3-inch flooring and reducing the number of stringers from eight to six. The standard type of trestle bridge for spans from 15 to 25 feet uses the same materials for floor, curbs and bracing, but employs six *CB* beams as stringers. To reduce the number of types and lengths of steel beams stocked, the following beams and sizes are at present considered as standard:

TABLE XXXIII.—*Standard beams*

Clear spans	Class of beam index	Weight	Nominal dimensions	Length	Material strength
Feet		*Pounds per foot*	*Inches*	*Feet*	
15 –17½	*CB* 101	21	10 by 5¾	19	Standard commercial.
17½–20	*CB* 101	21	10 by 5¾	21½	Standard commercial.
20 –22½	*CB* 121	25	12 by 6½	24	Standard commercial.
22½–25	*CB* 121	25	12 by 6½	26½	Standard commercial.

■ 98. CONSTRUCTION.—*a. General.*—The design contemplates two layers of floor planks 3 inches by 12 inches by 11 feet, one layer laid at right angles to the stringers and the other layer laid longitudinally but omitting three planks in the center of the bridge (see figs. 56 or 57). If traffic runs close to the curb these three center planks may have to be laid also, but with the traffic in the middle they will not be needed. Where there is need for haste, only one layer of flooring is essential initially and the second layer may be placed later. Stringers are lapped over the trestle caps. The 16-foot maximum length of timber is fixed by the fact that longer lengths cannot be readily carried in a 1½-ton dump truck. If round posts instead of rectangular ones are used, their diameters should be an inch larger than the greatest dimension of corresponding square timber, and if used for caps and sills they should be two inches greater diameter to allow for flattening on sides where stringers and caps or sills are secured. Squared timber should be used as caps and sills if possible.

b. Bracing.—Good cross and longitudinal bracing should be sound wood throughout without cracks, checks, knots, etc., so that the full strength of the nominal cross section may be developed in tension, if needed. As bracing is designed to carry tension only, it may be spliced with lap or fishplate joints. The clear unsupported span and least dimension of planks normally used for bracing (especially longitudinals) will prevent them from acting as columns to carry compression. Bracing should be cut with generous lengths so that the ends will project well beyond the points where they are nailed to posts, caps, or sills. If braces are cut too short, the nails may split the ends; if subjected to shock, the split ends will not hold and the braces will fail to act to provide the rigidity and stiffness intended in the trestle bent or span. No stock lengths of 2 by 10-inch bracing are carried; they are spliced as may be necessary. Bracing should be placed, when possible, so that it makes an angle of 45° with the vertical; and if there are two braces, so that they make an angle of about 90° with each other. Bracing for handrail posts is provided by letting a transverse floor plank project 3 or 4 feet outside the curb and cutting a short length of plank to fill out the other side. The handrail post is braced by a knee brace of similar size fastened to the end of the projecting floor plank and to the post.

c. Fastenings.—In making fastenings of flooring to stringers, two 60d nails are used in each stringer through each plank. Curbs are usually bolted to every third floor plank with ½- by 14-inch round bolts, but they may be toenailed for hasty construction. Stringers are best fastened to caps with drift bolts, but in hasty construction they may be toenailed and triangular blocks may be placed on the outside of each tightly spaced group of stringers to prevent the stringers from overturning. Drift bolting is the best method of

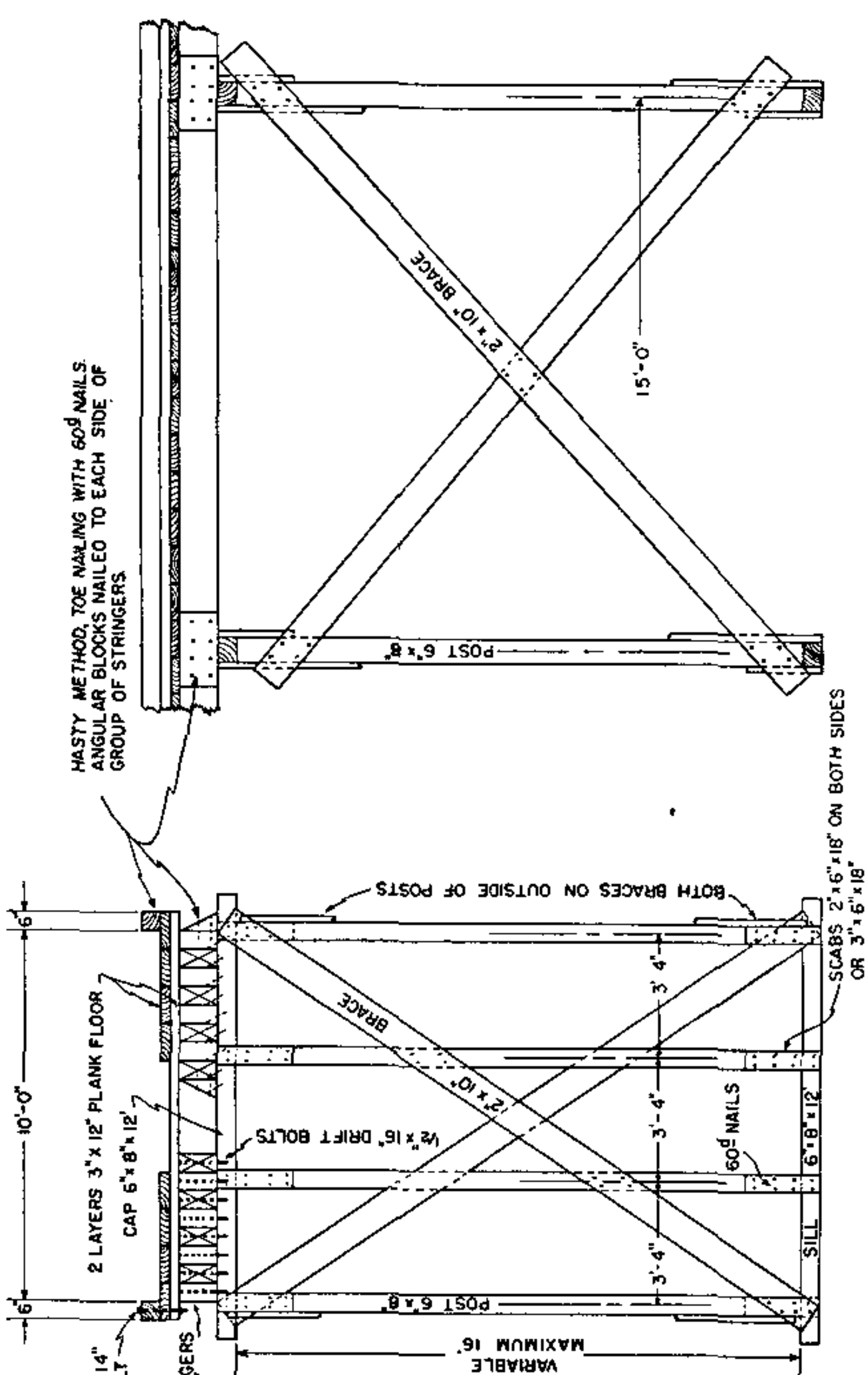

FIGURE 56.—Multiple short span (nonfloating) bridge for corps and army loads (H–15 loading). Main trestle members 6- by 8-inch timbers, used with wood stringers in spans up to 15 feet.

attaching caps and sills to the posts, but scabs will be used in rapid construction, using six 60d nails in the posts and four in the cap or sill (see fig. 56). However, in pile bents or trestle bents with round posts, drift bolts are required. Braces should be secured to all members they pass over by

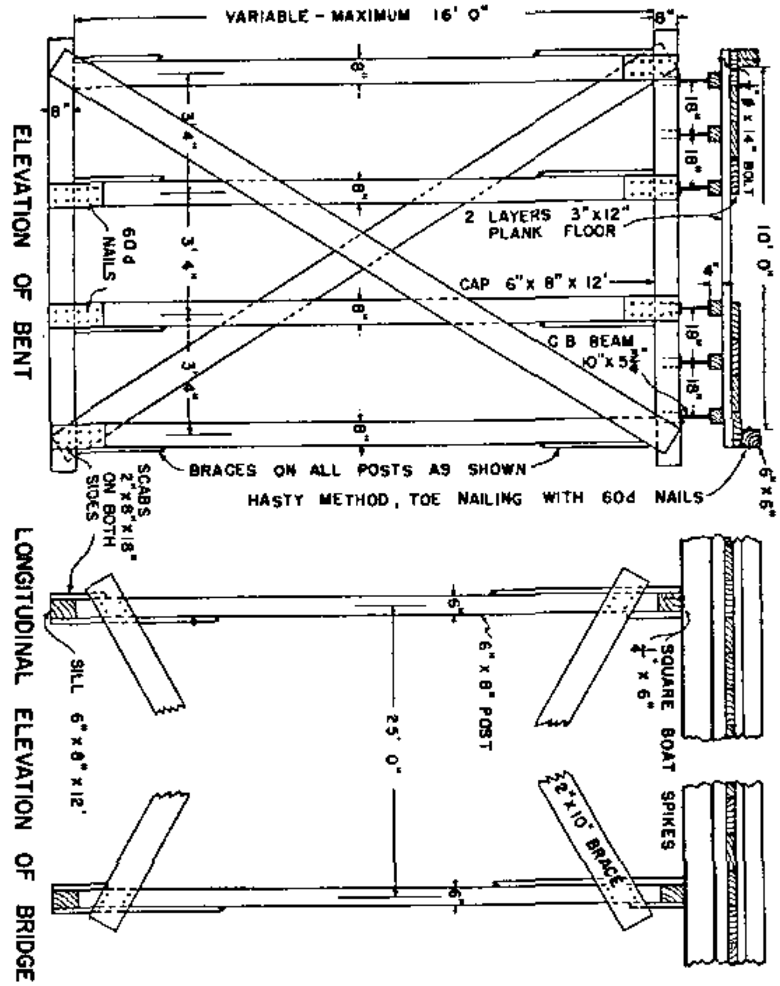

FIGURE 57.—Multiple short span (nonfloating) bridge for corps and army loads (H-15 loading). Main trestle members 6- by 8-inch timbers, used with steel stringers in spans up to 25 feet.

four 60d nails. For spans over 20 feet there should be longitudinal bracing on all four posts instead of on the outside only (see fig. 57). Wood-nailing strips, 4 inches thick, may be bolted or clipped on the top flanges of the steel beams used

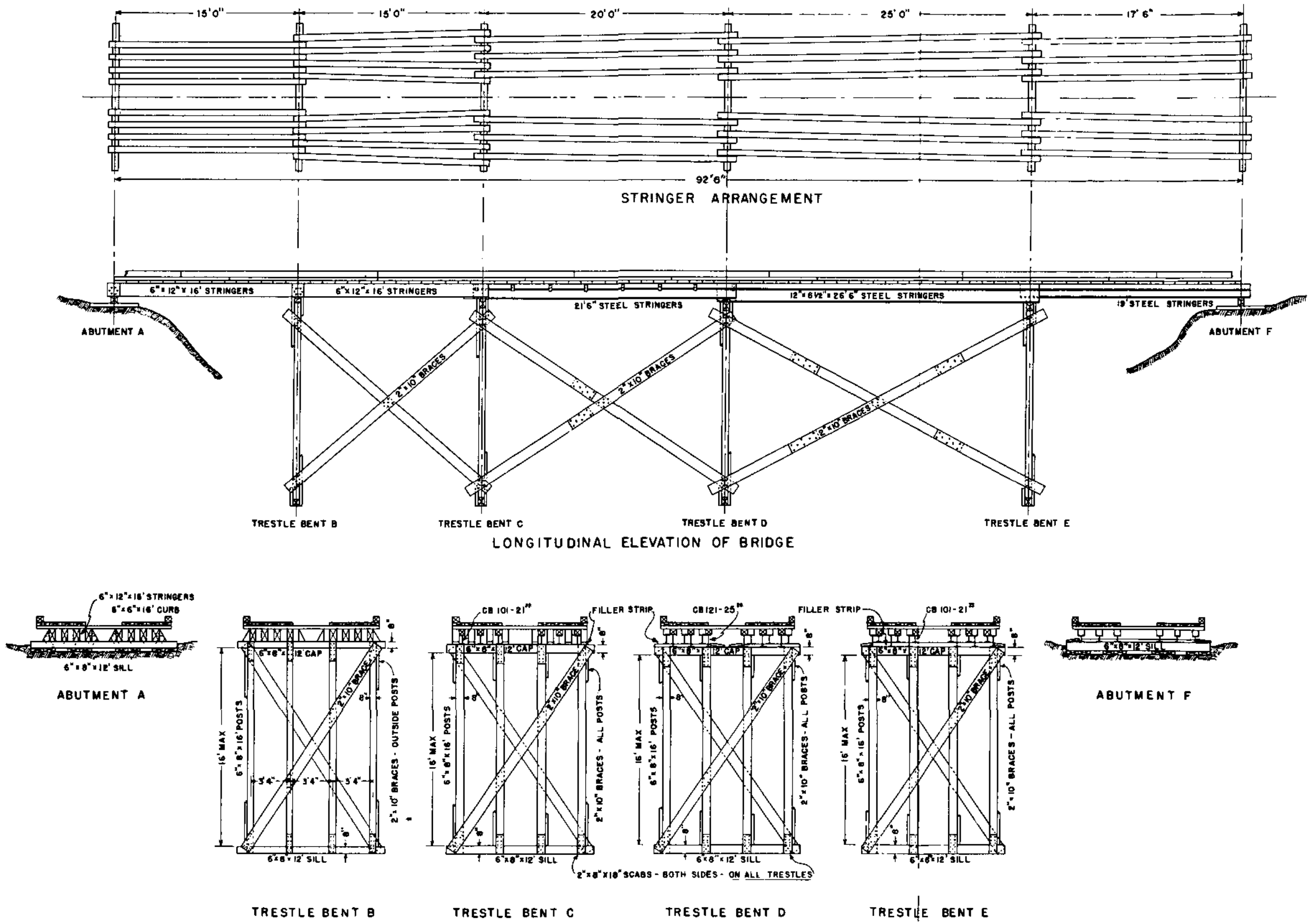

FIGURE 58.—Typical bridge, showing all types of trestles and stringers.

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for stringers. It is probable, however, that the beams will be supplied from depots with the nailing strips attached. The steel stringers are secured to the caps with a railroad spike on each outside edge of each flange or by two heavy 6- by ¼-inch boat spikes on each side driven through holes drilled at intervals on the lower flange near the ends of the stringers to accommodate the various lengths of spans. In figure 57 note the filler blocks used to raise the wood stringers to the top level of the nailing strips on the steel stringers.

■ 99. EXPEDIENTS.—When standard or appropriately dimensioned timber is not available for trestles, satisfactory sections may be built up of planks. This expedient should not be used for high trestles. A suitable trestle and stringer bridge for H–15 loading can be improvised solely from standard 3-inch by 12-inch by 11-foot floor planks. The length of these planks will limit the span to 10 feet, and the height of the posts to 11 feet. This bridge will require only 6 stringers consisting of two 3 by 12's nailed together and three posts for the trestle bent, with caps and sills made of two 3 by 12's spiked together. Bracing can be of 3 by 12's, also; curbs are made up of 3 by 12's split or ripped in half; and only one layer of the standard flooring need be used.

SECTION IV

STEEL TRUSSES

■ 100. PORTABLE, H–10, TYPE.—*a. General.*—The standard type steel truss bridge recently approved for military use is the "Portable Single Span (nonfloating) Bridge Equipage for Division Loads (H–10 Loading)." This bridge, mentioned briefly in paragraph 84 *a* (2) (*b*), consists of two sectionalized latticed box girders supporting a one-track timber deck. (See fig. 59.) The girders, sections 2 by 4 by 12 feet in outside dimensions, are made of a high-strength steel with all connections welded. The bridge will carry the H–10 loading on spans of not over 72 feet, and the H–20 loading on spans not over 36 feet. The intermediate girder sections are interchangeable end for end and top for bottom. With steep banks the truss may have the box girder at the ends, or, where the banks are more sloping, a special triangular 12-foot end section, which gives greater stability and requires less excavation for bank seats, may be used. The sections are connected together by eight longitudinal bolts secured through lugs at each joint as shown in figure 60. The bolts are carried in clips on each truss for shipment. Spools welded to the ends serve to aline the sections and act as shear locks under loads. The bridge is equipped with two launching noses to facilitate the placing of the girders as shown in the diagrams. Truss sections are dumped, alined, butted and bolted together in prolongation of the line of the bridge, and pushed into position over steel rollers, using the launching nose on the forward end to permit the girder to be rolled up the slope of the far bank. (See fig. 62.) This operation may be facilitated by using a block and tackle on the far end or by using additional sections and the second launching nose on the near end as a counterweight. Trusses may be placed by manpower under favorable conditions without the use of gin poles, power tackle, etc., although block and tackle, chain hoists, and jacks will assist in speedy erection under difficult conditions. The 12-foot planking, slotted at the ends like ponton chess, is secured in place by clamping it with modified C-clamps between the side rails and the outside top angles of the girders as shown in figure 61. This permits the flooring to be rapidly placed and removed for use elsewhere and avoids the necessity for securing wood nailing strips to the tops of the girders.

b. Weights of parts.—Each intermediate truss section weighs 1,140 pounds, the end section 820 pounds, and the erection nose 840 pounds. The weight of a 72-foot truss assembled complete with two launching noses and two end sections is 7,880 pounds, and the weight of all materials required for a 72-foot span is about 14 tons.

c. Auxiliary equipment.—To assist in putting the bridge into use rapidly, four metal ramps about 5 feet long have been provided to permit vehicles from the roadway to move onto the bridge without loss of time for backfilling and tamping, and to reduce the effect of too sudden load impact on the bridge. Other equipment, tools, and accessories are provided, such as ratchet wrenches, special rollers, jacks, blocks, rope, picks, and shovels. For a 60-foot span the necessary equipment can be carried in nine 1½-ton trucks or five 2½-ton trucks. For a 72-foot span one additional truck is needed in each case. Bulk rather than weight is the controlling factor in the number of trucks required.

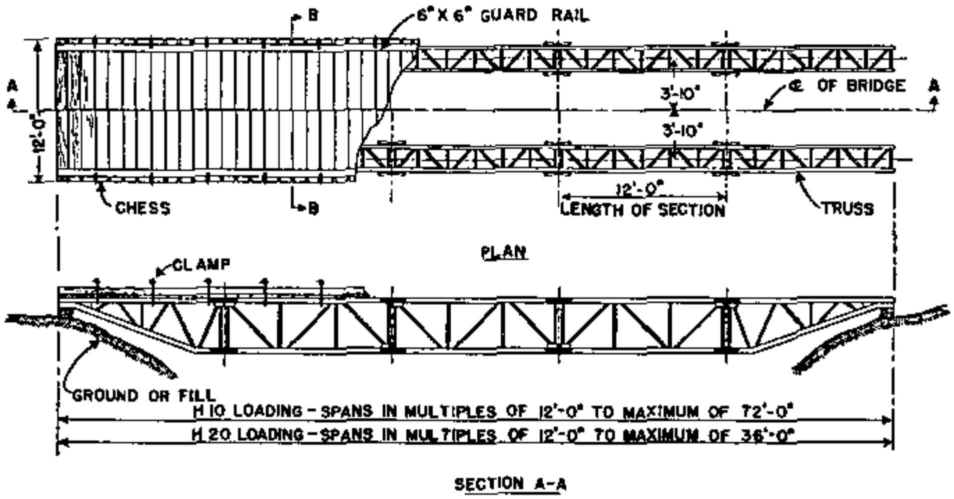


FIGURE 59.—Portable single span for division loads (H-10).

d. Erection crew.—Though the bridge may be erected by a crew of 16 men under a noncommissioned officer, the most efficient crew is one of about 40 men under an officer. The latter, when composed of experienced personnel, can erect the bridge in about an hour provided no unusual difficulties are encountered in the preparation of abutments and approaches. Inexperienced men will require about twice as long, and conditions of darkness, weather, fatigue, enemy activity, etc., will further increase the time required.

e. Construction for greater loads.—The H-10 trusses may be adapted to any length of bridge by the introduction of timber trestles or crib piers at intervals corresponding to the span lengths. In general, however, more permanent construction will be made use of under such conditions in order to save the portable truss bridges for real emergency uses. In emergencies, the loads sustainable by the portable truss bridges may be slightly increased if proper precautions are taken, such as keeping vehicles over the center line of the bridge, restricting speeds, allowing but one vehicle on the bridge at a time, and otherwise reducing impact. If loads in excess of 10 tons are to be regularly carried, however, the

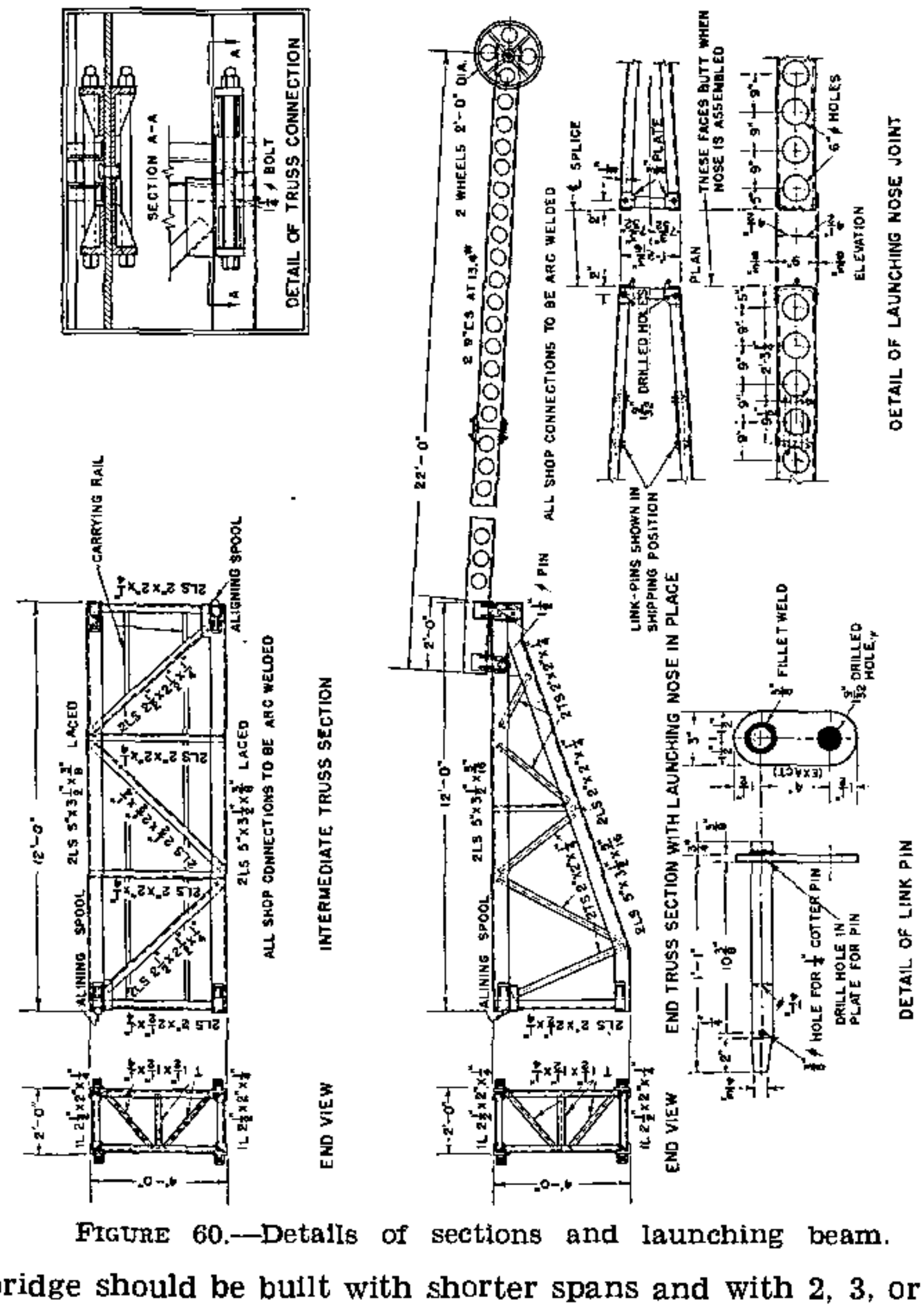


FIGURE 60.—Details of sections and launching beam.

bridge should be built with shorter spans and with 2, 3, or 4 trusses per span. Table XXXIV indicates the limiting loads that may be carried under such conditions.

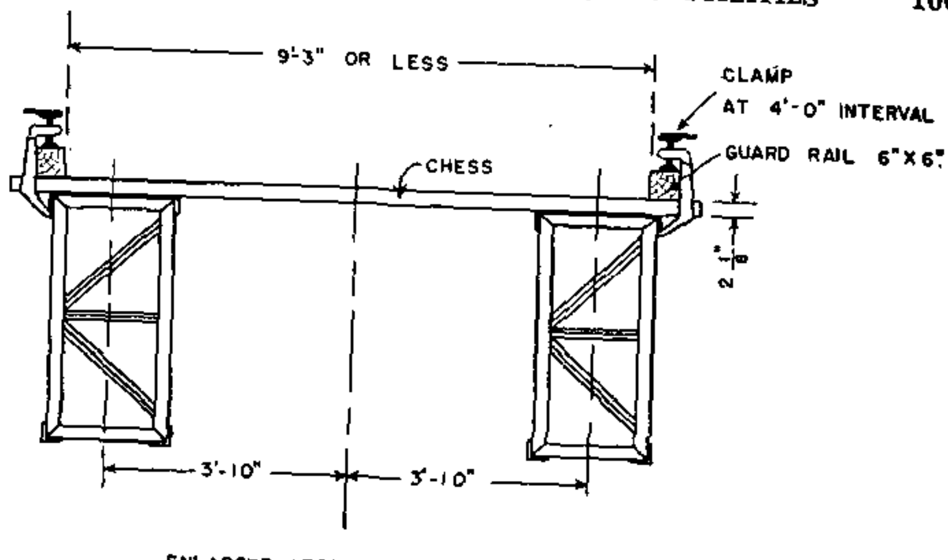


FIGURE 61.—Cross section of portable division (H-10) bridge.

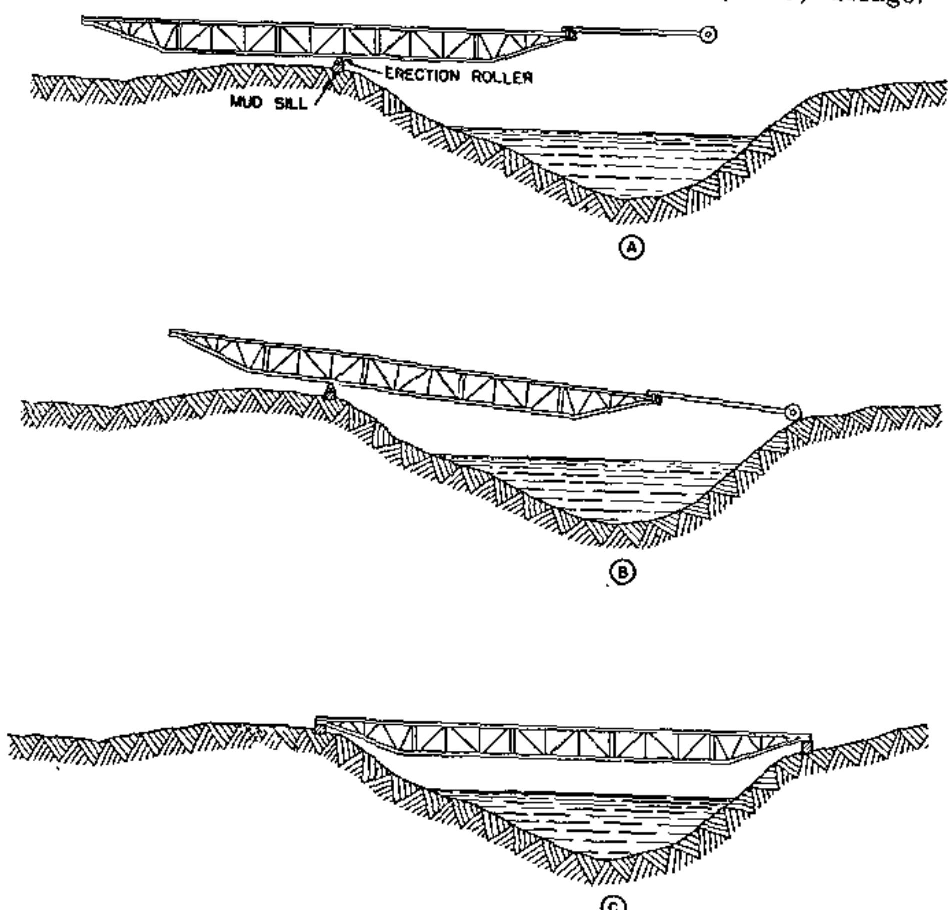


FIGURE 62.—Method of launching and installation on abutments.

TABLE XXXIV.—*Permissible loadings of portable, H–10, truss bridge under varying conditions*

Number of girders used	Length of spans						
	36 feet	48 feet	60 feet	72 feet	84 feet	96 feet	108 feet
2	H–20	H–15		H–10			
3			H–20	H–15		H–10	
4				H–20	H–15		H–10

In general, the use of each extra girder will increase the capacity of the normal two-girder bridge by approximately one-half of the original loading if the flooring distributes the load evenly among all girders. To carry the normal design loads, the use of one extra girder will permit increasing the length of bridge by two sections, and a fourth girder the increase of one more section.

■ 101. PORTABLE, H–20, TYPE.—A heavier, steel truss bridge of characteristics generally similar to those of the H–10 bridge has the name "Long Span (Nonfloating) Bridge for Corps and Army Loads (H–20 Loading)." The greater weights of this bridge generally require an extensive use of rigging and tackle for its erection. It has box-girder sections 2 by 6 by 12½ feet weighing 1,730 pounds each, and with two girders is capable of carrying all Army loads on spans up to 125 feet. The heavy timber decking will be secured by bolting or nailing. Because of the greater amount of time required for erection and its heavier type of construction, this bridge is used in areas some distance from the front. The total weight of the 125-foot span is about 43 tons. Steel truss bridges will not normally be carried by engineer troops in the field but will be stocked in depots.

SECTION V

IMPROVISED METHODS

■ 102. SHORT SPAN CROSSINGS.—*a. General.*—Though short span crossings cannot be standardized in the sense of those bridges just described, which are stocked in depots, they are nevertheless so common to the military engineer as to require some special consideration. The simplest form of crossing is a single span stringer bridge, adaptable to many crossings of narrow creeks and ditches. This type is described in paragraph 61. No supports are necessary other than the abutments, which carry the entire load of the superstructure. Embankments with culverts are adaptable to shallow depressions, especially when earth-moving machinery is available. Spar bridges furnish a means of effecting a rapid crossing of relatively deep and narrow ditches when only local materials are procurable.

b. Embankments with culverts.—These may be built to any height consistent with the requirements for drainage. When time permits, a very satisfactory crossing is made by laying a culvert to take the low water flow, placing a fill to moderate height, then paving and riprapping so that flash floods can be carried across the roadbed without erosion. Culverts are designed according to the principles laid down in paragraph 18.

c. Spar bridges.—This name is applied to bridges built of round timbers lashed together. Intermediate points of support are provided by inclined frames acting as struts to transmit weight from the middle of the bridge to the banks. The single-lock and double-lock bridges with two and three spans of 15 feet, respectively, are the ones of most utility. Spar bridges are not generally adaptable to the passage of heavy motor vehicles, but may be used in an emergency for foot troops and their accompanying combat trains. Figure 63 shows both a single- and double-lock spar bridge.

■ 103. ERECTION OF MILITARY BRIDGES.—Erection methods must be adapted to the kind of bridge and the conditions at the site. Trestles may be placed by hand, skidded into position, or erected by gin pole, derrick, crane, or A–frame. Figure 64 shows one method of erecting framed trestle bents. Stringers may be raised and placed by hand, tackle, or by the various lifts. Trusses may be erected on falsework, or pulled into place from their assembly position by a combination of tackle and derricks. Piles may be driven from traveling or floating mounts. A traveling power crane, equipped with hanging pile-driver leads and an air-compressor unit, is of great value in bridge erection.

■ 104. Repair of Existing Bridges.—*a. General.*—The rapid and adequate repair and maintenance of existing bridges is one of the most important duties of the engineer officer in the field. Partially demolished or weakened structures must be

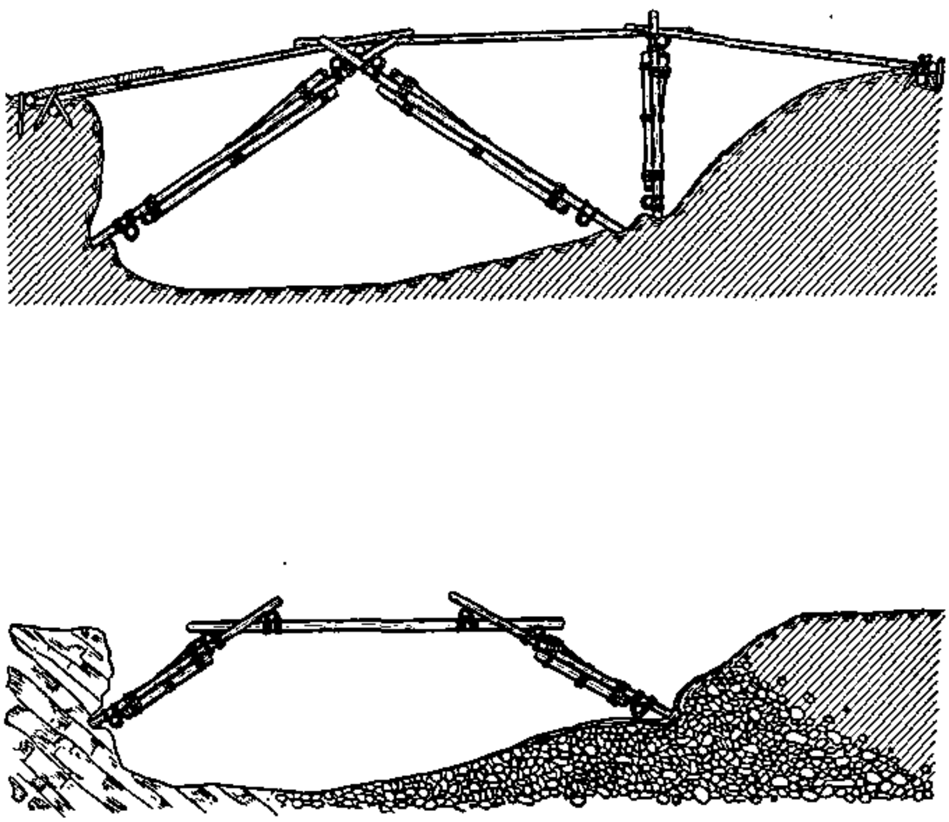


Figure 63.—Single- and double-lock spar bridges.

repaired and narrow bridges widened to meet the demands of divisional and army loads and increased volumes of traffic. This type of field engineering demands great ingenuity and common sense. The officer who cannot quickly devise means of making existing bridges carry the loads required by simple measures using available materials may be the cause of disaster, whereas one who can do so may be responsible for the success of the operation so far as making essential roads and bridges available for use is concerned. Results in military engineering must be attained with the greatest possible econ-

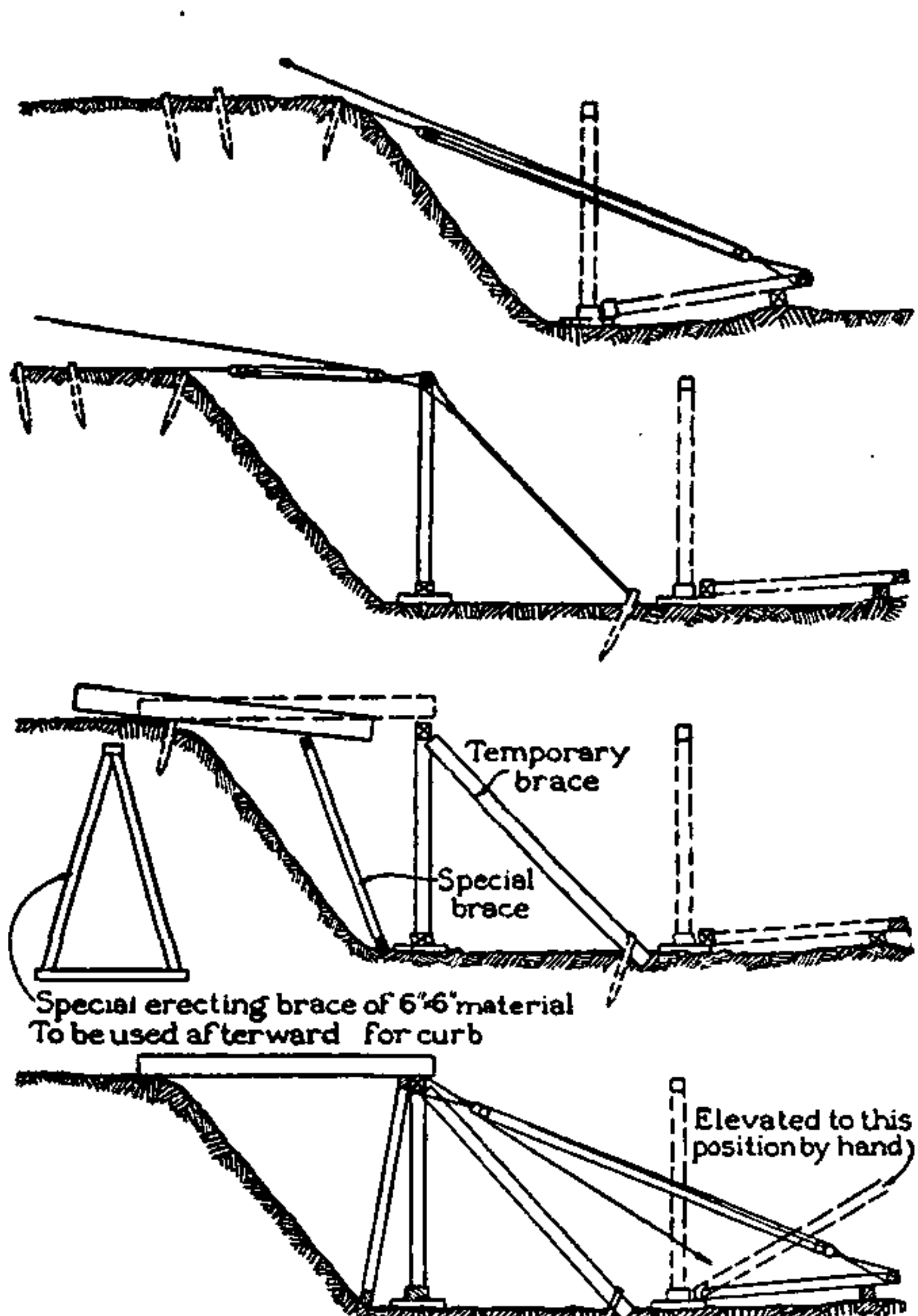


FIGURE 64.—A method of erecting framed trestle bents.

omy of time, labor, and materials. A new bridge should never be built if an existing one can be made to serve the purpose whenever less time, equipment, material, and fewer men are needed to strengthen the bridge, even though badly damaged. Under these conditions repairs should always be made rather than clear the site to build a new bridge or build a new bridge elsewhere. (See par. 73*c*.)

b. Types of repair.—The need for repairs to bridges should always be anticipated and determined by regular inspection of all bridges available for use. Before repairs are started a careful check should always be made to determine which portions require reinforcement and to what extent. Repairs will generally involve one or more of the following types of work:

(1) Strengthening the superstructure.

(2) Providing additional supports.

(3) Widening.

c. Suggested repairs and reinforcements.—(1) *Flooring.*—Additional layers of diagonal or staggered flooring or way-planking under tracks. A shallow layer of dirt, straw, or sod will protect the flooring.

(2) *Stringers.*—Additional stringers of smaller depth blocked tight against floor by double wedges with full bearing on caps, or jack up existing stringers on both sides to permit the insertion of a stringer of the same size as those already used. Sometimes stringers may be trussed with metal rods and blocks, as in the inverted king or queen post truss.

(3) *Supports.*—Trestles may be made stronger by the insertion of additional posts, providing additional material in the caps and sills and increasing the amount of cross-bracing, especially in tall bents. In some cases one or two new light bents may be placed next to an existing support and spiked thereto with short scabs. Decayed or damaged pile bents may be used by cutting off the damaged portions and splicing on new posts or by capping the old piles so as to place a trestle bent thereon. Weak joints may be strengthened by splices and scabbing or the use of metal dogs, which are large U-shaped cleats or staples whose ends are driven in the members to be joined.

(4) *Trusses.*—Truss members may be reinforced by placing additional wood or steel struts alongside compression members, and twisted cables, turnbuckles, or end-threaded rods, capable of being tightened up, beside tension members.

d. Methods of providing reinforcement.—(1) In the majority of cases the simplest method of reinforcement is to provide additional supports. Under favorable conditions one or more trestle bents or other support may be tightly wedged under the stringers to decrease the span and bending movements (see fig. 66). Knee braces, struts (fig. 66), or frames (fig. 65) supported on the piers or trestles may be used when no means of support for an intermediate trestle is available under the span, as over a very deep stream or gorge.

(2) Normally, the construction of an additional one-track bridge is preferable to the widening of an existing bridge unless a very considerable economy of time, labor, or material can be effected by the latter procedure. However, cases may arise where bridges must be widened for two or even more lanes of traffic, or be rebuilt with heavier construction for heavier loads and still not interrupt traffic. A wider and stronger bridge can be built on the same site as the existing bridge, one side being first completed and planked, and the other half finished later while traffic uses the completed portion. Where the present bridge is of ample strength, auxiliary bents may be placed alongside; in effect, a new bridge may be built adjacent to the old one. This may be done whether the old bridge is of masonry, steel, concrete, or timber construction. Narrow extensions, for the passage of foot troops, can be built outside one or both sides of a timber trestle bridge on brackets. Extensions of the caps supported by knee braces to the posts can carry the light stringers and flooring needed for sidewalks. Similar measures can be employed on other types of bridges.

(3) Demolished structures, such as trusses, can sometimes be repaired by hauling them back into position and blocking them in place on the original or new supports. Masonry piers can be leveled off and used to support trestle bents or carry trusses or stringers at lower than the original bridge elevation. A bridge may be reconstructed on old

supports or foundations by using the material from the demolished structures. Damaged abutments may be reinforced by framed cribbing or pile walls placed at the end and in front of them and backfilled with suitable material.

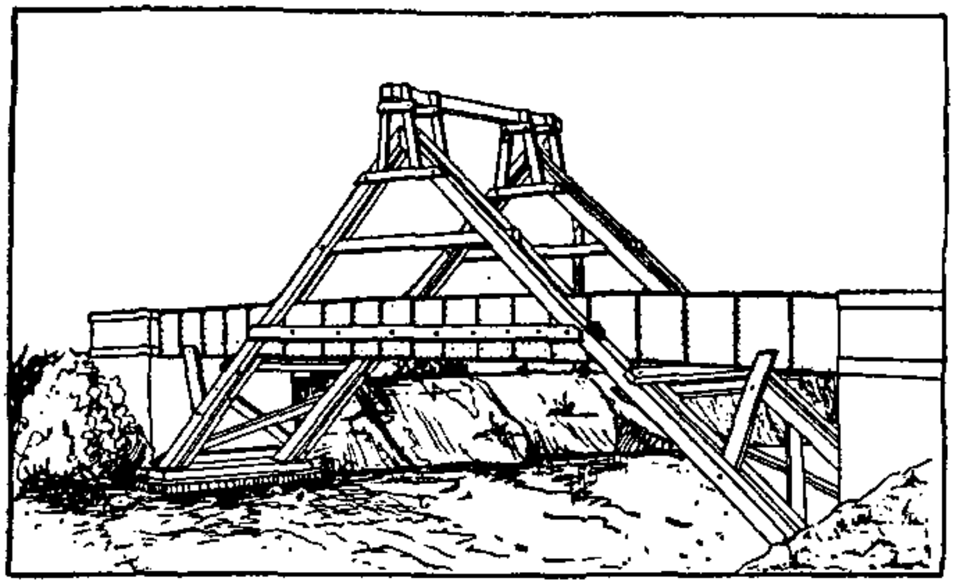


FIGURE 65.—Method of reinforcing girders with A-frame.

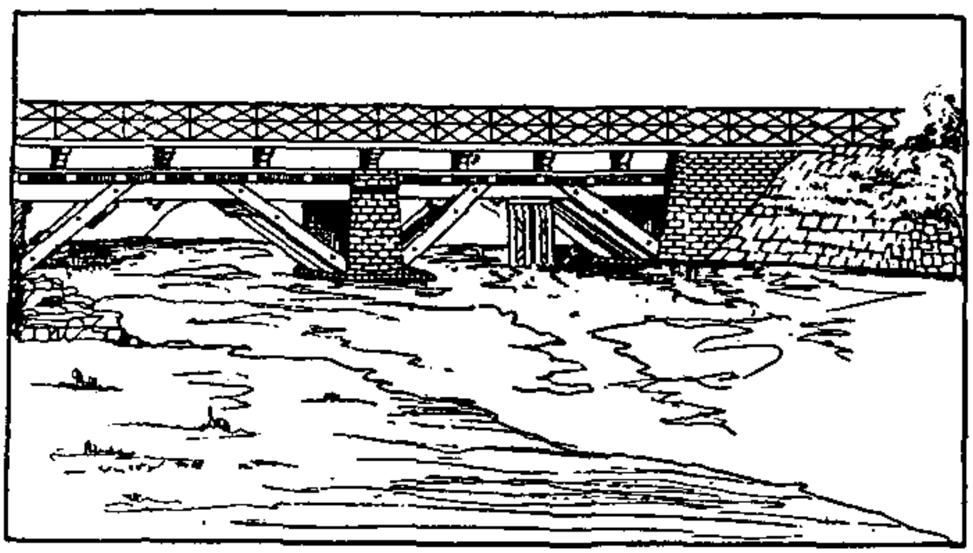


FIGURE 66.—Method of reinforcing floor with struts and intermediate trestles.

SECTION VI

SUMMARY

■ 105. SUMMARY.—*a*. Military bridges are designed for specific, limiting loads. It is therefore necessary, in each case, to determine existing and future requirements as a basis for the selection of the type of bridge to be employed. In considering a particular bridge type, reference should be made to tables of allowable loads, together with those showing the loads imposed by the vehicles which will use the bridge.

b. Standard bridges should be used in any emergency but should not be wasted by permanent employment in rear areas.

c. Drills, under conditions similar to those anticipated in the actual operations, are necessary for the development of efficiency in bridge construction by engineer troops.

CHAPTER 4

MEANS OF CROSSING STREAMS OTHER THAN BY BRIDGES

Section I

PASSAGE BY FORDS

■ 106. General.—Assuming moderate currents and hard bottoms, streams are, in general, fordable when depths do not exceed the following:

	Feet
For Infantry	3½
For Cavalry	4½
For Artillery (horse-drawn) and wagons	3
For trucks	2
For light tanks	1–3
For medium tanks	2–4
For heavy tanks	4–6

Whenever depths greater than 2 feet are found, the whole crossing must be examined carefully and used cautiously; such crossings are unreliable at best, being subject to sudden increases in depth as the result of flash floods, and to rapid deterioration under heavy traffic.

■ 107. Requisites of a Good Ford.—The requisites of a good ford are that the banks be low, but not marshy; that the water attain its greatest depth gradually; that the current be moderate and the stream not subject to sudden freshets and that the bottom be even, hard, and tenacious. These requisites are more cften met by mountain streams than by alluvial ones. Mountain streams, however, are more subject to freshets, and the bottoms are frequently covered with large stones, rendering wheeled traffic difficult. In level countries the bottom is likely to be of either mud or quicksand. Gravel is the best bottom.

■ 108. LOCATION AND PREPARATION OF FORDS.—*a. General.*—Fords are usually found in the wider and more rapid parts of streams. A stream not fordable at right angles can often be forded in an oblique direction between banks. Tracks leading into the water and reappearing on the opposite bank indicate a ford. A line of water differing in color from the water above and below it and extending unbroken across the stream frequently indicates a ford. Fords may be classified with reference to alinement as straight across (seldom found), diagonal, and dog leg (bend in midstream).

b. Methods of locating.—The simplest way to find the exact position of a ford is to send a number of mounted men across the stream wherever there is a probability of the river's being shallow enough. A still better method is to float down the stream in a boat, keeping in the swiftest part of the current where the stream usually is the deepest. Hold a sounding line over the stern at the proper depth, that is, the desired depth of ford. When this touches bottom, sound across the river directly or obliquely or both. When a ford is discovered, mark the ends and note prominent landmarks to identify it. Variation in depth can often be ascertained by inquiring of local inhabitants the variation from present stage. If the examination is to continue over a period of time, a simple gage. consisting of a graduated staff, may be devised. Where the current strikes a bluff there is always deep water, while on the opposite side there may be a shoal. A shoal is often indicated by a line of ripples with eddies on the downstream side. The ford, if there is one, will be above the line of ripples. A rocky or hard bottom may be located by noting outcrops of rock on the banks. The dog leg ford is often deeper near the banks than in the center, with the current divided by a gravel shoal at the angle of the dog leg.

c. Precautions in preparing.—(1) Dangerous fords should be marked by strong pickets driven into the river bed above and below the ford and connected with strong rope anchored to the shores.

(2) After a freshet the ford should be reexamined, and re-marked if necessary.

(3) A stream which is not fordable, due to short gaps of a few yards in which the water is too deep, may be rendered fordable by filling the gaps with hurdles loaded with stone and gravel.

(4) Fords in sluggish or muddy streams may be improved by covering the bottom with weighted bundles of coarse grass, rushes or brush, willow mattresses or other materials available locally. Where the bottom is very irregular, an earth or gravel fill may be placed and covered with chicken wire nailed to wooden crosspieces. Rolls of chicken wire alone frequently suffice to give stability to a relatively firm, sandy bottom. Large stones, likely to cause stumbling, should be removed or pushed to one side.

■ 109. Rules for Passage—*a. Maintenance detail.*—The ford should be placed in charge of an officer with a suitable detail of men. This officer is charged with keeping the ford marked, making repairs, providing for rescue of men washed away, and for a prompt and orderly passage in such formation as will do the ford least damage. He will confer with the commanding officer of the troops using the ford, and give instructions for passage which should be strictly observed.

b. Conduct of columns.—As a rule, Infantry pass in columns, rifles slung, the men in each rank holding to each other. Distance between squads should be fixed to prevent damming the stream. The men should loosen their equipment, incline their bodies toward the current, fix their eyes on the opposite bank, and not look into the water. In swift and deep currents, a rope stretched from shore to shore and held by the upstream man in each squad will make the passage less difficult. Artillery, trucks, and wagons pass in columns with distances sufficient to prevent damming. Cavalry pass in columns, usually of twos. Horses are not allowed to stop to drink when such halts would delay traffic.

c. *Special precautions*.—It is depth of water, swiftness of current, and muddiness of water that introduce elements of danger. Animal tracks leading to approaches on both sides are deceptive and may be merely watering places for animals on each bank. Information should always be secured from trustworthy local inhabitants in case of doubt, and it is well to watch them cross before those inexperienced attempt it. If needed, boats or rafts should be secured and stationed on the downstream side to rescue men and equipment washed away. If boats are not available, a life line should be stretched on casks or other floats.

d. *Passage of motor vehicles*.—In crossing fords with a motor vehicle, the height of the battery terminals and carburetor in the vehicle will determine the depth of water which can be negotiated under its own power without stalling. Almost all military vehicles can be driven through water less than 2 feet deep or knee deep. Crossings should be made slowly (less than 5 miles per hour) in low gear to prevent splash and so the fan and belt will not throw water inside the hood. If the fan blades dip in the water it is advisable to disconnect the fan belt. Reconnaissance of fords for motor vehicles should be made on foot, with special attention to locating boulders. Heavy loads may be removed from trucks and carried by hand to gain the corresponding raising of the truck body on the springs and to prevent the danger of stalling.

e. *Paved fords*.—Paved fords are in general use for crossings of wide, shallow arroyos or washes of arid regions frequently met with in the southwest. These channels often carry water only during sudden severe rainstorms, and to provide bridge structures large enough to carry these large but infrequent flows would be an uneconomical use of labor and materials. The road across the wash may be built slightly below the natural elevation of the streambed to prevent scour, and paved with timber, cobblestones, telford or other macadam, and, if very important, even with concrete. The alinement should be straight and the pavement location shown by four marking posts, two at each end, which can also be marked as gages to indicate the depths of water during floods. To carry small, dry weather stream flows a small culvert may be built under the center of the paved ford. In this same connection see paragraphs 18*d* and 102*b*.

SECTION II

PASSAGE ON ICE AND BY SWIMMING

■ 110. GENERAL.—Large bodies of troops can seldom make a successful stream crossing on ice or by swimming. Such means should be regarded as expedients only and should be employed only after a thorough consideration of all eventualities. In the case of a planned crossing on ice, a slight rise of temperature may so weaken the ice as to bring about a failure of the entire operation. Similarly, unexpected changes in the current may preclude the swimming of even small groups across a stream.

■ 111. PASSAGE ON ICE.—*a. General information.*—The bearing power of ice varies greatly, being contingent on both thickness and condition. Ice is generally thicker near the banks than in midstream. Before effecting a passage, the thickness of the ice should be tested over the entire stream by cutting holes at short intervals. New, sound ice in floating contact with the water will bear the following loads: 3 inches, small groups of men; 4 to 5 inches, Cavalry in small groups; 7 inches, wagons and 75-mm guns; 9 to 12 inches, divisional loads; over 20 inches, Army loads.

b. Reinforcing.—(1) Two tracks of planks laid on ice to bear the wheeled traffic will increase the bearing power of the ice. Wagons may also be transformed into sleds by fastening planks under the wheels. Sand, gravel, cinders, straw, etc., thrown on ice make a better footing for men and horses.

(2) In freezing temperatures, the thickness may be increased by flooding the surface of the ice, retaining the water by a small earthen dam. The thickened ice should form a belt three times the width of the desired roadway. Six to eight inches of straw laid on the passage and flooded will, when frozen, considerably increase the bearing power.

(3) When the river is frozen on each side but open in the middle due to a swift current, a boat, or other surface obstacle, placed across the interval, will often check the velocity enough to permit freezing.

c. Precautions.—The passage should be made under the supervision of an officer who is responsible that the means and methods of passage are such as to give the greatest degree of safety consistent with military necessity. His instructions should be strictly complied with. Careful consideration should be given to the possibility of hostile artillery breaking holes in the ice during the passage of troops.

■ 112. PASSAGE BY SWIMMING.—*a. General information.*—It is often necessary to make a surprise landing on the enemy side of a strongly defended stream or canal before any bridging operations can take place. In strongly defended positions, such a surprise landing can often be effected only by swimming across, sometimes under cover of darkness. Moreover, in numerous instances, small patrols operating in hostile territory will be forced to swim streams encountered in their patrolling. Hence, troops should be trained in swimming across streams with the aid of a few simple expedients.

b. Preparations.—(1) The manner of crossing the stream will depend to a great extent upon the tactical situation, the width of the stream or canal, and the velocity of the current.

(2) Where the situation demands it, a covering detachment composed of the best swimmers is sent across first to cover the crossing of the remainder.

(3) The crossing of narrow streams or canals with little or no current velocity may be effected without the removal of any of the clothing or equipment, the better swimmers assisting the poorer swimmers. If the stream be wide or the current swift it will be advisable for the men to remove their equipment and perhaps a part of their heavier articles of clothing. These should be wrapped and securely tied in the shelter tent half with the rifle on the outside readily available. This bundle, if properly tied, may be floated for a limited time, and may be either pushed across by hand

or towed by a rope around the waist. It may also be floated across on plank floats when these are available.

(4) If desired, ropes may be stretched across the stream to assist in the crossing. This may be accomplished by having good swimmers carry across a small rope to which is tied the larger rope to be used. The rope to be used is stretched tight and tied to tree trunks or strong stakes on opposite banks so that it hangs at about the surface of the water. Floats may be used to keep it at this height. It may be used to assist in the crossing of those who cannot swim, to aid the poorer swimmers, or to serve as a life line in swift currents.

c. *Floats and individual rafts.*—A plank, approximately 3 inches by 10 inches by 10 feet, will serve to support a fully equipped soldier. Smaller planks will serve as an aid. The soldier after removing his equipment, wrapping it in a bundle, and tying it on his back, can lie flat on a plank and paddle across a stream of moderate current and width. Over greater distances such a method of crossing is very laborious and is likely to be unsuccessful.

Section III

PASSAGE BY BOATS, RAFTS, AND FERRIES

■ 113. General.—Usually the crossing of the initial waves of the covering forces will be by means of boats, as only in rare cases can the passage be made by fords, swimming, or on ice. If boats are locally available in any quantity, they may be used for this purpose. Normally, however, the standard assault boat will be used, supplemented by ponton boats or rafts. A brief description of the assault boat and the technique of its use is given herewith.

■ 114. Assault Boat.—*a. Description.*—The assault boat is of a conventional skiff type, with a flat bottom, a square, slightly sloping stern, and a pointed bow; it weighs about 200 pounds (fig. 67). The skin is of ¼-inch fir plywood, highly resistant to the effects of moisure. Seven paddles of the ordinary canoe type are provided with each boat for propelling it when fully loaded.

b. Capacity.—With 6 inches of freeboard in the stern and 12 inches at the bow, the displacement of the boat is approximately 3,200 pounds. It will safely carry (with the men fully equipped) any of the following loads:

(1) Eleven men.

(2) Ten men, one .30 caliber machine gun and its tripod, and 13 boxes of ammunition.

(3) Ten men, one .50 caliber machine gun and its tripod, and 4 boxes of ammunition.

(4) Nine men, the 37-mm gun (old model) on its wheels, and 4 boxes of ammunition.

(5) Nine men, the 81-mm mortar, and 50 rounds of ammunition.

(6) Nine men and the equipment of the advanced echelon of the infantry battalion communication section.

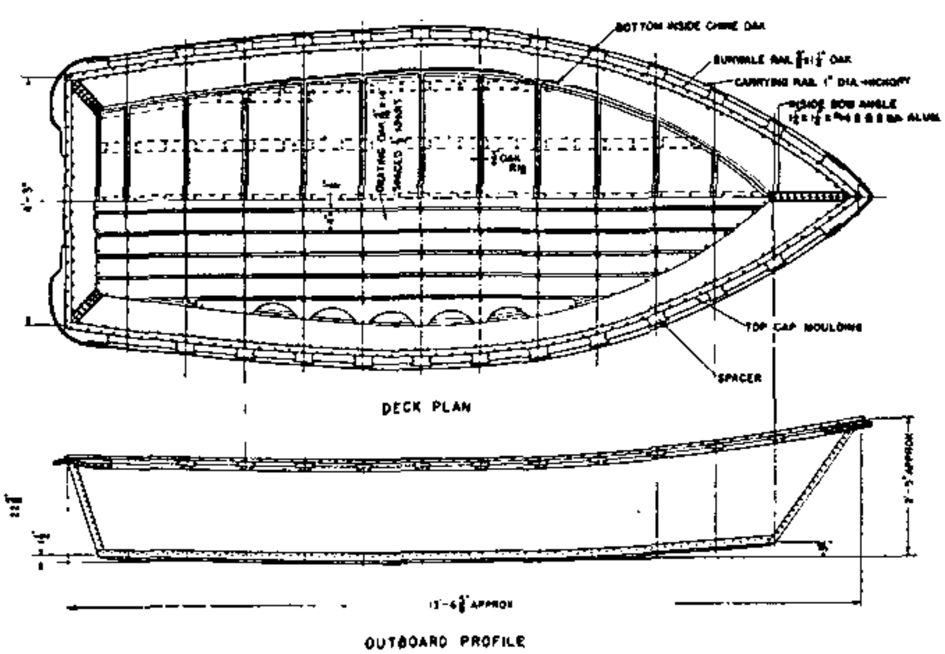


FIGURE 67.—Plan and side elevation of assault boat.

If a crew is used, these capacities are reduced by the number of men provided for this purpose. The available space, rather than safe buoyancy, limits the capacity in each case.

c. Transporation by truck.—Ten boats are nested for transport as a standard load for the 1½-ton truck (fig. 68). When more than 10 are carried the load becomes too high, top-heavy, and unwieldy; also there is danger of damage to the lower boats in the pile. On trucks with narrow bodies when the load of the nested boats would be carried on the handrails of the bottom boat, wide timber blocks should be provided on the floor of the truck. This blocking will raise the bottom boat so its gunwales are above the sides of the truck.

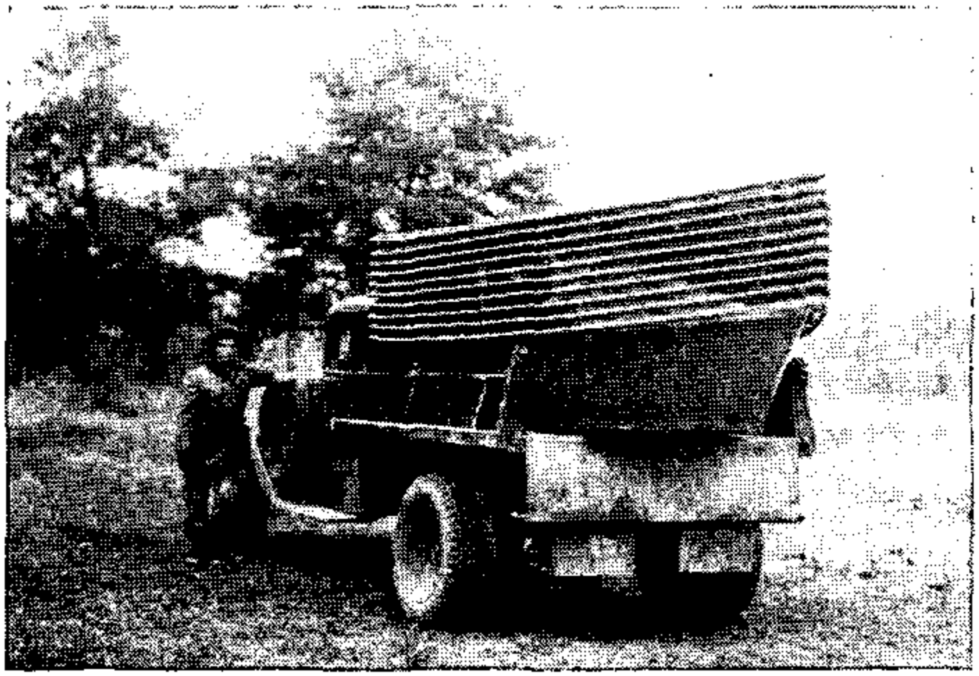


FIGURE 68.—Engineer $1\frac{1}{2}$-ton dump truck with normal load of 10 assault boats.

d. Storage and care.—When not in use, the boats should be kept under cover; before being placed in storage they should be cleaned, dried out, and painted if necessary. The boat has so few seams, well protected by metal strips, that only rarely will there be any necessity for soaking it before putting it into the water after a long period of dry storage. The boats should be handled with considerable care; they are designed and constructed so as to be as light as possible, and hence are less durable and more fragile than heavier types. Major repairs to the skin should be made with moistureproof plywood. Ordinary standard olive-drab oil paint is suitable for these boats. Patches may be made of thin metal sheets and nails, preferably of copper. Bullet holes may be plugged temporarily with wads of cloth or paper, pegs, adhesive tape, putty, and chewing gum.

e. Function.—The primary function of the assault boat is to furnish a rapid means of crossing streams for the troops and weapons of the initial combat waves in the attack of river lines. Assault boats are normally continued in use as a crossing means (supplementing other forms of equipment) until adequate bridging facilities have been put into operation or until the need for them no longer exists. Two engineers are usually provided as a crew to act as guides and return the boat for each new trip. The engineer personnel is charged with the proper use and operation of the boats while they are being carried to the bank and when crossing the water.

f. Final assembly area.—The final assembly area is the area designated in orders where engineer troops, assault boats, and Infantry meet and from which the assault boats are carried to the river by the Infantry. The assault boats are moved to this area, unloaded, and disposed for ease in carrying to the river. Some desirable characteristics of the final assembly area for a crossing force are:

(1) Ease of access for vehicle or hand transport bringing up the assault boats.

(2) Defilade (protection from artillery and rifle fire).

(3) Concealment from ground and aerial observation.

(4) Numerous foot routes to river easily followed by carrying parties.

(5) Proximity to crossing fronts.

(6) Width enough for foot routes spaced widely apart over entire crossing front.

g. Movement to the river.—The following general considerations should be observed:

(1) The passengers and crew comprising the first wave carry the assault boat from the final assembly area to the near bank on the crossing front and launch it in the water. Not more than ten men (fig. 69) should carry the boat and at least four should be used even for a short carry.

(2) From the time it leaves the final assembly area until it reaches the far bank, an assault boat should not stop its

forward movement except for loading personnel and equipment.

(3) This movement should be along the most direct route practicable. Flank movements parallel to and near the river bank are dangerous and should be avoided.

(4) The movement from the final assembly areas to the river should be made by all practicable routes available. It should start on orders of the engineer officer in charge of the boats at each final assembly area at such times as will permit all boats of the first wave to arrive at the river

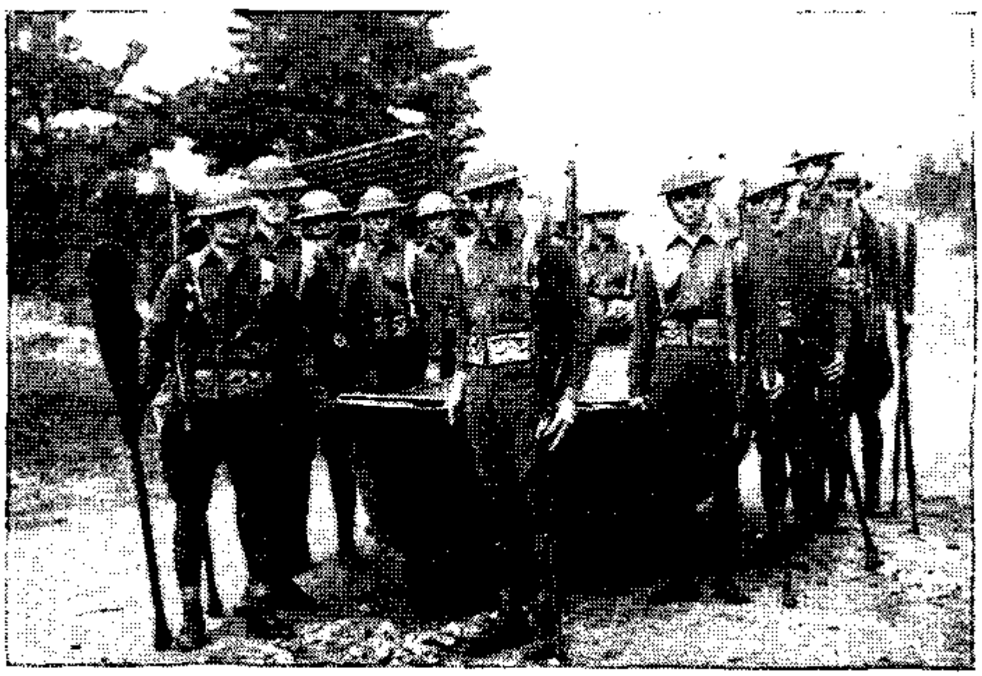


FIGURE 69.—Carrying party with assault boat.

bank at approximately the same moment (H-hour). Well-marked routes and guides are essential. Bunching on a few of the most suitable routes forward is most undesirable and may be disastrous.

(5) Because the assault boat is resonant, like a large drum, every effort must be made to prevent loud noises caused by objects striking the sides or bottom. Nothing should be carried in the boat while in transit. Paddles should be carried in the outside hand so that they cannot touch the boat. Rifles and other equipment of the carrying

party should be slung so that they do not strike against the boat. The boat should not be allowed to strike stumps, branches, or other obstructions, and should not be dropped or dragged on its bottom on the ground.

(6) The engineer at the bow acts as guide; the engineer in charge of the boat and the infantryman in command of the infantry detail follow close behind the boat.

h. Launching and loading.—Immediately upon arrival at the river bank, the boat, without change in the carrying formation, is carried, bow first, into the stream until water at least deep enough for free flotation of the loaded boat is reached. Ammunition boxes, machine guns, etc., are quietly placed in the boat. Then the passengers enter, keeping the boat in balance and taking care to prevent the thumping caused by heavy footwear or weapons hitting the boat. In shallow water care must be taken to prevent the added weight from grounding the boat, causing noise and delay, which is particularly dangerous at this time. Paddlers, with rifles slung on their backs, should kneel on the knee next to the outside of the boat. Other passengers crouch low in the boat, holding their rifles vertically with butts down. One engineer paddles in the bow; the other, who commands the boat while on the water, in the stern; he is the last one to enter the boat. He sees that the boat is properly balanced, that passenger paddles are properly distributed, and then gives, in low tones, the command to shove off. When the water close to the bank is very deep, the boat, with bow pointing upstream, is held at the bow and stern by the engineer crew and loaded directly from the bank.

i. Crossing the water.—The attacker usually has the best chances of success if he so times the crossing that the initial wave arrives at the far bank shortly before daylight. Individual boats are kept well separated along the unit's crossing front. Each starts across as soon as loaded, and proceeds rapidly to its landing point by the most direct route. Under some conditions of fog, smoke, or darkness the course may be set by the use of a luminous compass. No attempt is made to maintain any specific formation while on the water. Paddles should be held well away from the carrying rail along the gunwales, to avoid thumping, and should be used without splashing. Passengers should not shift their weight during the crossing. Shooting from the boat is prohibited. All men should be prepared to slip off their packs or belts if the boat is sunk. If the boat capsizes and floats, it should support all men if they will hold on and work it toward the closest shore.

j. Disembarkation and subsequent action.—Upon arrival at the opposite shore, the beaching of the boat, except on a soft bottom, is avoided. Passengers lay their paddles in the boat, step ashore or into the water quickly and quietly, unload any cargo, and then pass to the control of their leaders for combat. The engineer crew promptly paddles the boat back on the shortest line possible for another load. Rapid currents will carry all boats downstream a predictable distance during a round trip. Hence the loading points for each boat should be corresponding distances downstream for all waves after the first. It is frequently impracticable to return boats at night or under fire to their original points of departure, especially if the current is swift. Subsequent waves follow the initial wave from the assembly area at such times that they will arrive at the bank just prior to the time the boats return thereto. Engineer units and assault boat equipment attached to an infantry unit in a river crossing normally revert to engineer control when the entire infantry unit (less the personnel and vehicles which will cross by other means) has been landed on the far bank.

■ 115. PONTON BOATS.—Ponton boats of the 7½-ton ponton bridge (model 1926) may also be used for the purpose of ferrying troops more rapidly after the initial waves have crossed and the danger of aimed small-arms and artillery fire has been removed. If rowed, the capacity of the model 1926 ponton is 25 passengers with a crew of 6 rowers and a steersman. If an outboard motor is used, the capacity is 35 passengers with a crew of 3.

■ 116. PASSAGE BY RAFTS.—*a. General.*—In passages requiring transportation of comparatively large bodies of troops, sufficient boats may not be available. In such cases rafts must be constructed from material available locally. The type of rafts constructed will vary from large structures designed to carry a comparatively large force, and prepared with deliberation when no enemy opposition is expected, to small floats to aid the individual soldier to effect a crossing under actual enemy opposition.

b. Advantages.—The advantages of a raft are that it gives a far greater carrying power than a boat for the same buoyancy of support, and also may be used to transport artillery and cavalry. The disadvantages are the time required for construction and the difficulty in handling the more cumbersome structure.

c. Construction of two-boat raft.—(1) To construct this type of raft, lay 5 to 7 beams of the same thickness across

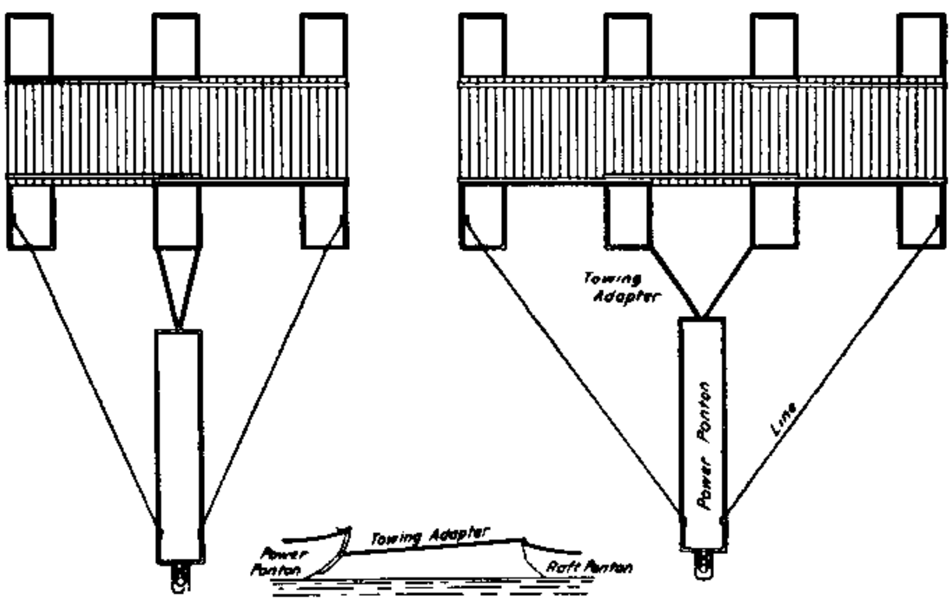


FIGURE 70.—Raft from equipage.

two boats. Lash these beams to the boats and place floor planking on the beams secured by side rails placed over the outer beams and either lashed or nailed to them. The size of beam depends on the load, boat interval, and boat capacity. Figure 70 shows a similar type raft constructed from the 7½-ton ponton equipment, model 1926, using 3 and 4 pontons.

(2) Similar rafts may be constructed from the newer types of ponton equipment which will carry correspondingly heavier loads. A four-boat raft with pontons at normal

intervals is needed to carry a section of horse-drawn field artillery. The horses should be unhitched and the wheels braked and chocked. Ropes or brush rails around the edges of the raft will help to prevent nervous animals from getting frightened during the crossing. The use of one or more of the 22 hp outboard motors to propel the raft, where secrecy is not involved, will speed up the crossing and place more troops and guns across the stream than would be otherwise possible. (See fig. 73.)

(3) In emergencies, rafts may be constructed from logs and plank. However, such rafts are not recommended, as they are very bulky and cumbersome, and are correspondingly difficult to handle. In this country, such rafts should be constructed from dry timber if possible, as practically no local green timber has sufficient buoyancy to be of much value in a raft.

d. Cask supports.—Satisfactory rafts may often be constructed with cask supports, for use in an emergency. Several instances are recorded where small rafts, built up of gas cans, casks, and the like, were used to form emergency footbridges.

e. Passage rules.—The same rules apply to the passage of troops on rafts as in boats, attention being paid to the following: Rafts drift more than boats, consequently the landing on the opposite shore will be farther downstream; as the embarkation is easier, there is more danger of overloading the raft and of confusion in embarking. Infantry enter in single file, first occupying the middle line of the raft; a rank is then added alternately on the up- and downstream sides until the raft is loaded. Artillery, heavy carriages, and horses are placed in the center.

■ 117. PASSAGE BY FERRIES.—*a. General.*—The types of ferry commonly used are the rope ferry, the trail ferry, and the flying ferry, the last two being also known as trail bridges and flying bridges. The use of the 22 hp outboard motor, furnished with some types of ponton equipment, will greatly increase the speed and efficiency of any of these types of ferry and allow them to be used to good effect where the current or wind would make this otherwise impossible. A cable stretched across the river may be used to pull the boats back and forth by hand and decrease the time required for crossing on all types of ferries.

b. Rope ferry.—The rope ferry, which is used in streams with sluggish currents, consists of either a raft or a suitable boat, drawn by hand or poled along a rope or chain stretched from bank to bank. A rope ferry may be constructed by laying a cable or chain across the stream, anchoring its ends, and taking three or four turns around a windlass mounted on the side of the barge or raft used. An old wagon wheel may be utilized as a windlass, or a truck with a snatch-block may be similarly employed. The safety of a ferry, especially when transporting animals, is materially increased by the construction of guardrails and end gates.

c. Trail and flying ferries.—Where the speed of the current is as great as 3 feet per second, it can be utilized to propel the raft. To accomplish this the sides of the raft are held at an angle of 55° to the current. Such ferries are known as trail ferries when fastened to a traveler on a cable stretched across the river, and as flying ferries when fastened to a fixed anchorage upstream. (See figs. 71 and 72.) Although these ferries do not afford a continuous communication, they possess the following advantages:

(1) They are readily established, even in the most rapid currents.

(2) They require but little material for their construction.

(3) They may be operated by very few men.

(4) They permit the passage of troops of all arms, and of animals and vehicles.

(5) The entrance to and exit from them is easy.

(6) They are not likely to be injured by floating bodies which, either by accident or design, are carried downstream by the current.

Trail and flying ferries should be located in straight reaches of the river, and landing stages should be built on both banks. With these ferries it is sometimes difficult to reach the landing. In such cases a line buoyed in their track and attached to the landing may be used to pull them in, and poling may be resorted to in order to push them out into the current.

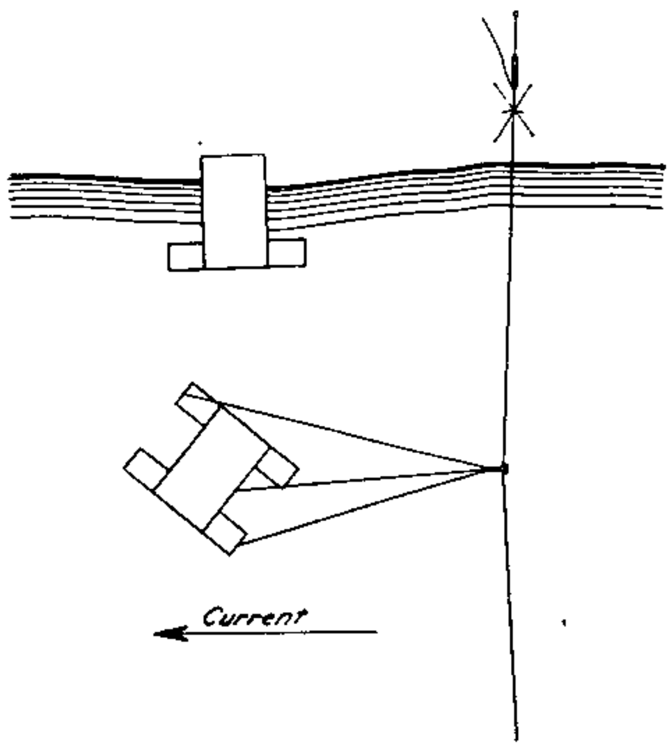


FIGURE 71.—Trail ferry with landing stage.

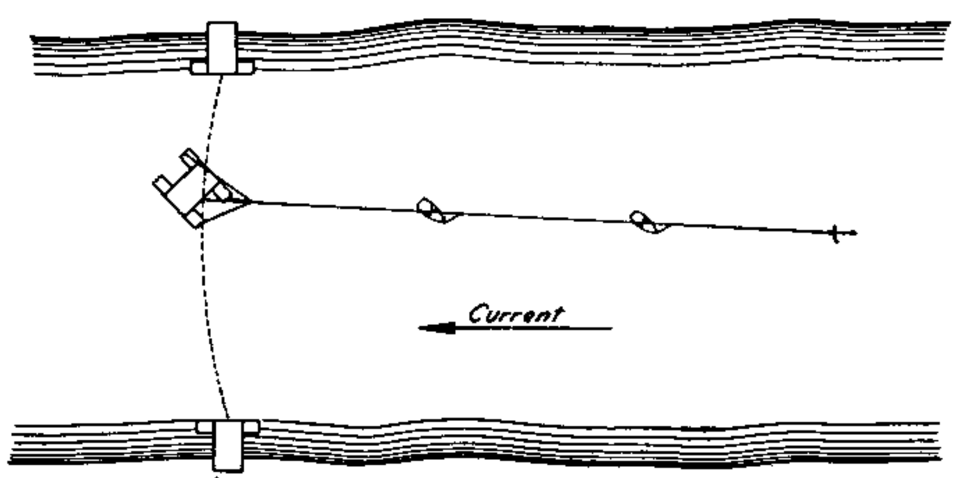


FIGURE 72.—Flying ferry.

d. Expedients for ferrying.—(1) Canvas well stuffed with hay or other light materials furnishes a support of considerable buoyancy. To use it in this manner a light frame of poles is built on the canvas and filled with material for stuffing. The canvas, which has previously been well soaked, is brought up over the stuffing and its edges well lashed together. Care should be taken to cover the corners of the frame with hay. An improvised boat can be made by covering a wagon body with paulins.

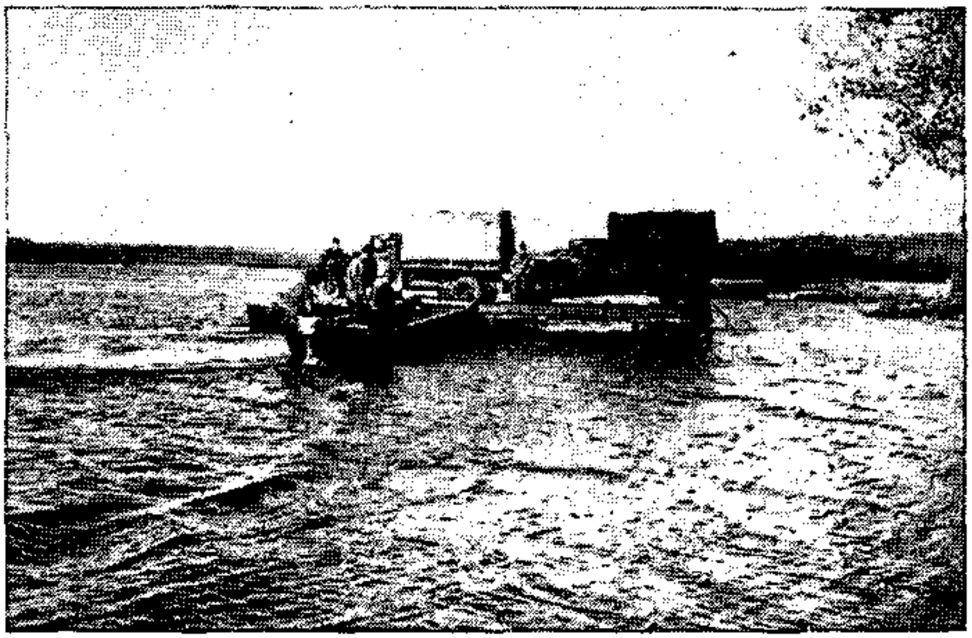


FIGURE 73.—Outboard motor on ponton pushing raft ferry.

(2) In addition to the methods given, individual ponton boats of any of the various types available, barges, or similar boats of any type may be used singly as ferries, especially while there is great need for the movement of troops and supplies across the river before the completion of a ponton or other type of bridge. If sufficient equipment is available, this means of ferrying should be kept available and used when there is a possibility that existing or newly constructed bridges may be destroyed by artillery fire or air attack, with no alternative means of crossing within a reasonable distance.

(3) Other than motor boats, one of the best means of propelling pontons, rafts, or other boats used as ferries is the outboard motor furnished with the 7½-ton ponton bridge (model 1926) (fig. 73). Four 22 hp outboard motors of standard commercial design will be supplied with each ponton unit. Various methods of mounting the motor on the ponton have been tried, and a standard bracket design for this purpose has been adopted. The assault boat described in paragraph 115 is too weak and light to use this motor, but one of 4½ hp has been adopted for use with an assault boat that has been designed and is undergoing test as an accompanying boat for the ponton units. This boat is intended to be used for reconnaissance of sites, taking soundings, patrolling the bridge, and for other similar uses.

CHAPTER 5

MILITARY RAILWAYS

SECTION I

GENERAL

■ 118. GENERAL.—The term *military railways* includes all railways under military control in the theater of operations and all those which have been turned over to military authorities in the zone of the interior. The Corps of Engineers is responsible for the construction, maintenance, and operation of military railways in the theater of operations.

■ 119. RAILWAYS IN WAR.—Railways are superior to any other form of land transportation for bulk movements of supplies and troops over distances greater than about 75 miles. Since the location of railway lines may be of great strategic importance, and because long lines are difficult to construct in war, many countries have laid out their regular transportation systems with a view to employing them in military operations. Railways in rear of the battle line and parallel to it have a distinct value in connection with the rapid movement of troops from one part of the front to another.

■ 120. GOVERNING CONSIDERATIONS.—*a. General.*—Although the fundamentals of operation and maintenance of military railways are generally the same as those prevailing in peacetime in the United States, there are several distinct differences. Outstanding among these are the greater emphasis on economy of men, materials, and labor, and the general sacrifice of personal comforts and convenience in time of war.

b. Location and construction.—In the construction of new lines prompt completion is of primary importance. Therefore, earthwork should be reduced to a minimum, even at the expense of mileage, curvature, and gradient. No attempt is made to build for permanence beyond the probable duration of the war.

c. Equipment.—Equipment existing in the theater of operations will be used to the greatest extent possible. When new equipment is procured, such types are selected as will give the greatest amount of service for the duration of the war, and with the least amount of maintenance. Standardization is important and simple types are preferable.

d. Roadbed and track.—Roadbed and track will be as light as is consistent with the objects to be attained, neglecting most of the refinements of the modern railway.

e. Operating rules.—(1) Train operation is governed by a military railway operating code which is based upon the Standard Code of Operating Rules of the Association of American Railroads.

(2) Freight equipment is loaded to its capacity and unloaded and released promptly at its destination. In most cases, trains are operated at low or moderate speeds, dependable arrival at destination being the primary consideration.

(3) Superimposing the operation of military trains upon an existing civilian train schedule, especially in a foreign theater in friendly territory, requires careful planning by officers of the railway service, strict attention and study on the part of train and engine personnel, and the use of the greatest tact by all. In hostile or unfriendly territory special attention must be paid to means of preventing sabotage. Local methods of operation should be employed whenever possible.

f. Maintenance standards and safety rules.—Maintenance standards will be such as opportunity permits, and arbitrary safety rules become secondary to military necessity and the mission. Facilities for maintenance of equipment near the front are limited. Shops are established well in the rear to minimize enemy interference. Rapid repair or replacement of parts or units must be the rule to which monetary considerations should be subordinated.

■ 121. ADAPTATION OF COMMERCIAL LINES TO MILITARY USE.—*a. Basic considerations.*—From an engineering standpoint the most desirable characteristics of a military railway system are—

(1) Yard, terminal, and shop facilities properly located.

(2) Double or multiple track.

(3) Seasoned roadbed (stable and well drained), heavy rail, and good ballast.

(4) Light grades and curvature.

(5) Adequacy of passing tracks and side tracks.

(6) Bridges of sufficient strength for military loads, including railway artillery.

(7) Loading, unloading, and storage facilities where needed.

(8) Short mileage between important points.

(9) Line and facilities not subject to damage from natural causes.

b. Importance of adequate terminal facilities.—In estimating the capacity of a railway line each of the above elements must be duly considered, but the outstanding requirement is that of adequate terminal facilities, for if cars cannot be unloaded and returned promptly the line will become quickly congested. An increase in terminal capacity can be secured frequently by adding tracks and driveways to permit loading and unloading by hand.

c. *Detour plan.*—When the main lines to be put to military use have been decided upon, a detour plan must be devised for the alternative routing of traffic in case a part of the line is put out of service by normal accident or enemy activity. This applies particularly to choke points in sections carrying the heaviest traffic. Points of weakness in a line are tunnels, bridges, deep cuts, and high fills.

■ 122. OPERATING DIVISIONS.—The military railway system in a theater of operations is divided for purposes of administration into *railway grand divisions* and *railway divisions.* The railway division is the primary administrative unit for the operation and maintenance of standard railways. The limits of the railway division are such that the division superintendent can maintain personal supervision over all activities within his jurisdiction. These limits are determined by the length of main line, the number and location of branch lines, the density of traffic, and terminal facilities; they should be such that the division superintendent can reach any point on his division within his working day. The length of a division may vary from 50 to 120 miles. The limits of a grand division are determined by the military situation, the traffic to be expected, and the geographical locations of lines and facilities, and will include two or more railway divisions. The layout of a typical railway grand division is shown in figure 74.

■ 123. REGULATING STATIONS.—*a. Purpose.*—A regulating station is an agency in the system of supply for the field forces which directs and controls the movements of troops and materials by rail to or from the area which it is specifically designated to serve (usually one per army area). The traffic beyond the regulating station up to the railheads consists of a number of standard carloads of maintenance articles per day per military division at the front, plus any special requirements, all exclusive of ammunition which is sent in special trains from advance ammunition depots. A regulating station may be called upon to send, on short notice, a replacement of a daily train which may have failed to reach its railhead because of accident, enemy interference, or other reason. In order to be able to comply with such emergency demands, a number of tracks are set aside at the regulating station on which a few loaded standard trains are held for immediate forwarding. Although not strictly a function of a regulating station it may be found necessary to provide a small amount of storage at these stations for commodities known as regulating station reserves, to safeguard against any break-down in the lines of communication.

b. Facilities.—The facilities required at a regulating station consist of—

(1) A railway yard with receiving, classification, and departure tracks.

(2) Tracks for loaded emergency trains (rolling reserves).

(3) Limited storage space for regulating station reserves.

(4) A small warehouse with transfer platforms to facilitate the handling of less-than-carload shipments.

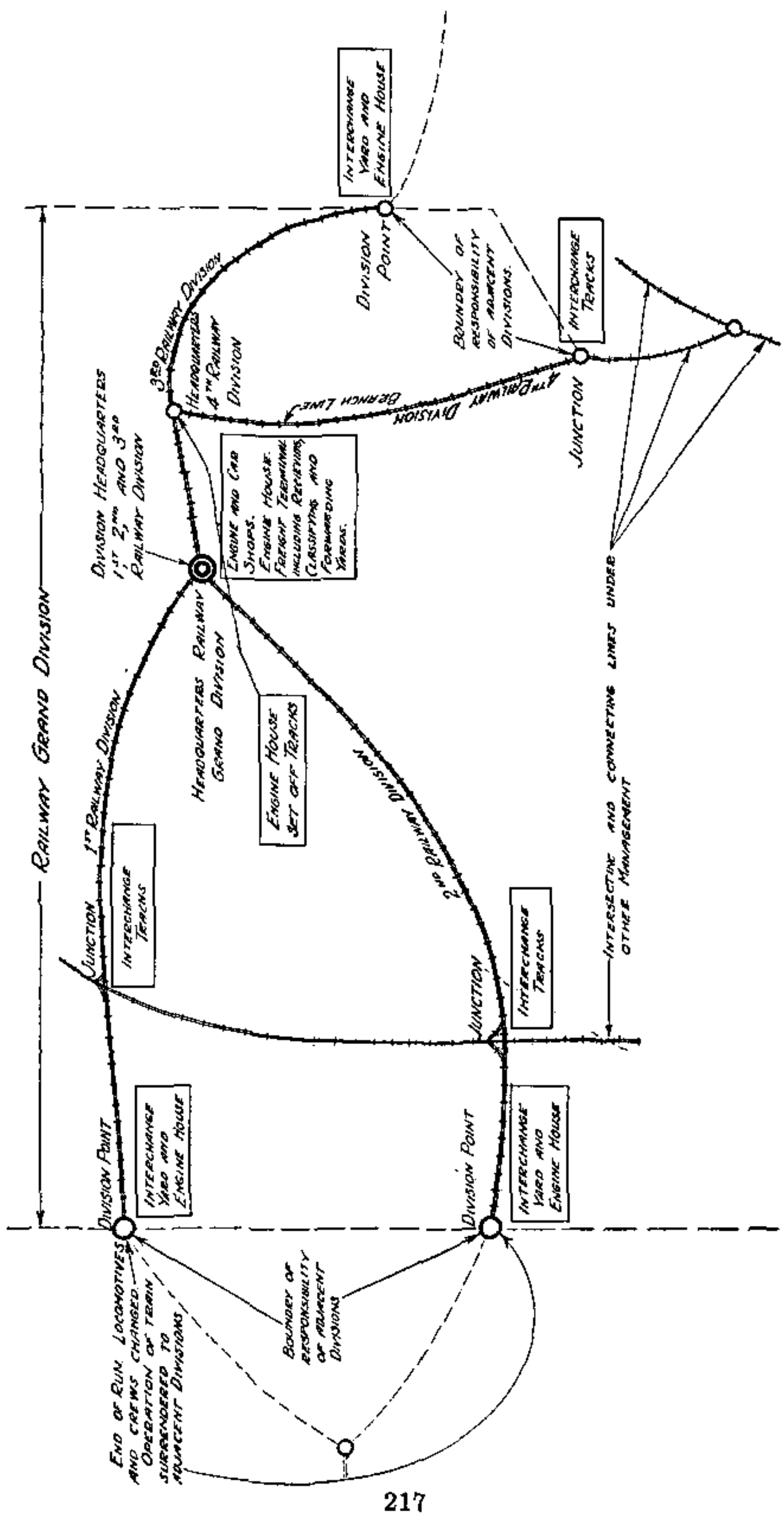


FIGURE 74.—Typical railway grand division.

(5) Barracks, mess halls, and hospitals for handling casual transients.

(6) Facilities for detraining, exercising, watering, feeding, and resting animals.

(7) Engine terminal facilities.

A regulating station serving one field army should have at least 25 tracks, each approximately 1,500 to 2,000 feet in length, in its yards.

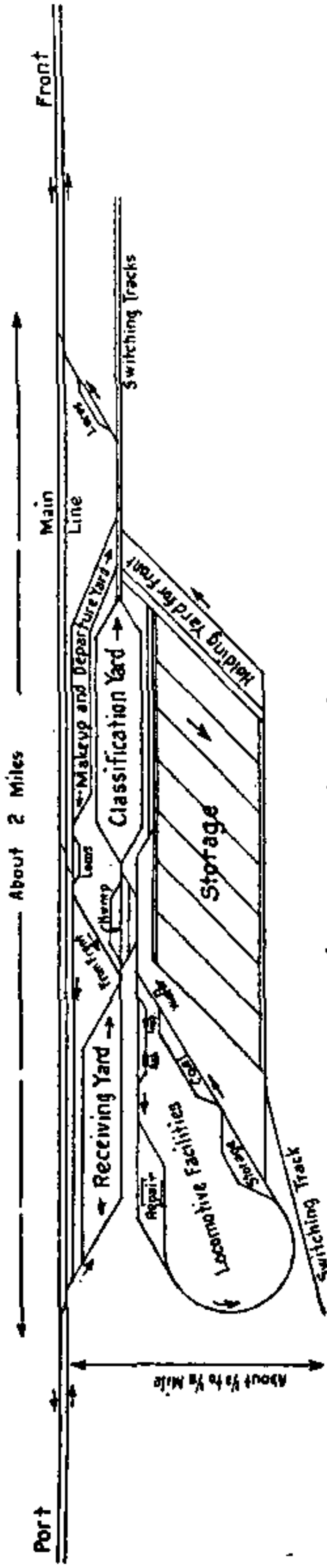
c. Location.—The regulating station should be located at a point where the main line from the rear branches into several lines running to the front and should be upon, or have access to, a belt line permitting rail movements through the regulating station to be routed laterally along the front when required by the military situation. A point where existing railway facilities are ample is usually selected for use as a regulating station in order to avoid, if possible, any new railway construction. An existing terminal is, in most cases, suitable for a regulating station, although the necessary shelter and storage facilities may have to be constructed.

d. Layouts.—Figure 75 shows a typical layout of a regulating station.

■ 124. RAILHEADS.—*a. Description.*—A railhead is a point on on the railroad in the theater of operations at which supplies for troops are discharged, and from which they are distributed or forwarded to other points. It may consist of a highly organized railway station with sidings and storehouses, or it may be merely a place where the railway runs near a highway where supplies are transferred to the vehicles of organizations. Normally, it consists of some installation between these two extremes. The railhead is generally chosen so as to utilize existing rail facilities. The question of what facilities are necessary depends upon whether the railhead is to serve one or more large units (division, corps, or army troops) and whether it is to be used simply for the receipt of daily automatic supplies of food and fuel, or whether large amounts of supplies such as engineer materials are to be received. In case a railhead is serving a single division with daily automatic supplies only, the essential facilities include—

(1) A siding long enough to accommodate the daily train.

(2) Ample roadways for approach and departure.



(Parallel Yard Type)

FIGURE 75.—Schematic plan of a typical regulating station layout.

(3) Space for accommodating the organizational vehicles while loading.

(4) Parking space for waiting vehicles.

If the situation is such that it is impracticable to transfer the daily supplies directly from the railway cars to the organizational vehicles, the railhead should include some sort of storage facilities. These should be such as are necessary to accommodate a limited quantity of stores for emergency use, plus 1 or more days' supply of rations, forage, fuel, and other articles of approximately uniform daily consumption, from which supply trains of the combat troops may be filled without holding them for the arrival of the railway trains. In this latter case a warehouse consisting of a standard open-sided shelter or barrack may be constructed, or tents may be used for the storage of articles which must be protected from the weather. Where a railhead serves a number of large units and handles all classes of supplies, including large quantities of engineer and ordnance supplies, a number of ladder or spur tracks may be necessary, and these may have to be constructed. The organization of the railhead may also require in this case the construction of a considerable amount of roads to enable the organizational vehicles and supply trains to have access to the railway cars and storage places. A typical railhead is shown in figure 76.

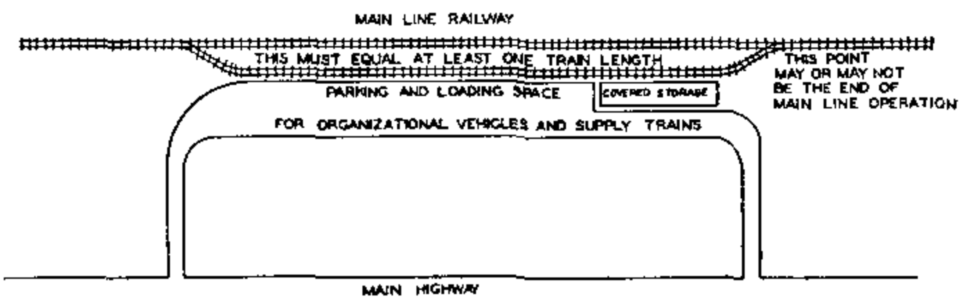


FIGURE 76.—Typical railhead for serving a single infantry division with daily supplies.

b. *Requirements*.—An ideal railhead should meet the following requirements:

(1) Utilize the existing railway net.

(2) Be convenient to the existing road net.

(3) Be convenient to the units served by the railhead.

(4) Utilize existing facilities, such as warehouses, spurs, unloading platforms, etc., wherever possible.

(5) Be located so as to avoid cross traffic with the trains of units served by other railheads, and so as to eliminate any need for crossing the railway tracks by the trains of the units served.

(6) Be located beyond effective enemy artillery range.

(7) Be within an area protected from mechanized attack or air attacks.

(8) Provide convenient and adequate cover and concealment for the trains.

(9) Other considerations being reasonably equal, it should, of course, be located at the site which can be developed with the least work.

■ 125. FUNCTION OF GENERAL ENGINEER TROOPS.—Construction of new railway lines and facilities in the theater of operations is a function of general engineer troops. These troops may also be assigned to railway divisions or grand divisions for maintenance of way when such maintenance is beyond the capacity of the railway operating battalions. Special equipment for heavy maintenance is under the control of headquarters, railway grand division, and is assigned as required. (See FM 5–5.)

■ 126. RAILWAY CONSTRUCTION.—*a. General.*—The construction of new main track in the theater of operations is unusual. Existing trackage and facilities are utilized and exploited to the fullest extent, but it will be found that new facilities must be provided and existing facilities adjusted to meet the conditions of war. These facilities will include yards, side tracks, fuel and water stations, signal systems (including telephone and telegraph lines), and engine houses.

b. Captured lines.—As the army advances, captured enemy lines will be reconstructed as required. Availability for immediate service, rather than permanence, is the controlling factor in the type and character of construction.

c. Fundamentals governing construction.—The following general fundamentals will govern in the construction or rehabilitation of facilities in the theater of operations:

(1) Care must be exercised in the location and plan of layouts to secure the facilities required for present and future military operations. Bare necessity, however, will be the controlling criterion. Ballasting will be used only when without it the tracks will not carry the rolling stock. General track surface should be only good enough to meet immediate requirements, with provisions made for its improvement as the need arises.

(2) Water and fuel stations in the theater of operations will consist of any suitable facilities that are available, or that can be adapted or improvised.

(3) The signal system on new or rehabilitated lines will be of the simplest kind. Automatic block signals and interlocked switches may be used and maintained when already existent. A crossing may be protected by a manually operated gate and a telegraph office provided with a manually operated board or flag. Train dispatching is preferably accomplished by telephone on account of its simplicity and the fact that trained operators are not required at outlying stations. Dispatching by telephone has the added advantage that by equipping isolated sidings with a telephone box for the use of train crews the movement of trains is frequently facilitated in emergencies. When existing telegraph lines are taken over wholly for military use, it is of advantage to convert them to telephone lines if it is expected to use them for any considerable time. Wire circuits are constructed and maintained by the Signal Corps except when used exclusively by the military railway service, in which case the maintenance is taken over by engineer railway units.

(4) The roundhouse with its usual adjunct, the turntable, is to be avoided in any area subject to bombardment by enemy aircraft on account of its easy recognition from the air. New engine houses should be simple, rectangular, frame structures without complicated doors or windows, and provision should be made for turning locomotives on wyes or loops. In cases where a roundhouse and turntable are part of the existing facilities taken over for military use, precautionary measures should be taken to insure that engines will not be cut off and rendered useless in case the turntable is disabled. Alternate exit tracks constructed for this purpose

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should be camouflaged if possible and not used except in emergency.

SECTION II

RAILWAY RECONNAISSANCE

■ 127. INITIAL RECONNAISSANCE.—When a new theater of operations is entered, a comprehensive reconnaissance of the railway situation is made at once, and an early report of the condition and capacity of the existing facilities is made in order to permit intelligent planning by the tactical staffs. The first reconnaissance of the railroad need not be extensive, but should aim at discovering quickly the general condition and capacities of the roadbed, track, motive power, cars, and terminal facilities, and formulating an estimate of the amount and kind of engineer work necessary to render the facilities serviceable for the immediate needs of the military force. This information is gained from every available source, including airplane photographs, reports of reconnaissance detachments (of all arms), interrogation of civilian employees of the railway lines, files of the railway offices, and personal reconnaissances by the unit engineer and his assistants. In making this hasty reconnaissance the following points should be noted:

a. Gage of the lines.

b. Whether the line is passable throughout, and if not, at what points and for what reason stoppages of traffic may occur.

c. The actual number, types, condition, and nature of engines and cars available.

d. The number, capacity, location and length of trackage sidings at stations and other points where troops with impedimenta may be entrained and detrained.

e. Stocks of fuel and railway maintenance material on hand.

■ 128. DETAILED RECONNAISSANCE.—After the military authorities have taken over the control of operations of an existing railway line, a complete and detailed survey is made of the facilities. This survey is for the purpose of informing the unit engineer of all the facts pertinent to the operation and maintenance of the line, and shoulder cover in detail the following points:

a. Local name of the railway.

b. Terminal points and distances between stations.

c. Gage.

d. Track—whether single, double, or multiple.

e. Condition of roadbed, ties, and rails.

f. Ruling grade and maximum curvature.

g. Number, length, and location of passing tracks.

h. Location of grade crossings.

i. Drainage and liability to overflows or washouts.

j. Facilities for repair.

k. Condition of right-of-way for marching troops along the line.

l. Number, location, dimensions, and strength of tunnels and bridges.

m. Number and nature of engines and cars.

n. Available capacity for transporting troops and supplies between given points.

o. Location and capacity of shops and store yards.

p. Name and location of stations with facilities for entraining and detraining troops.

q. Sidings and capacities.

r. Platforms.

s. Ramps.

t. Turntables.

u. Water tanks.

v. Fuel supply.

w. Storage facilities.

x. Derricks and cranes.

y. Signal communication.

This reconnaissance is usually made under the direction of the commander of the engineer railway unit which is to operate and maintain the line. The data, once obtained, are kept current by periodic and specific reports.

■ 129. CAPTURED RAILWAYS.—A reconnaissance of railway lines captured from the enemy presents a special problem, since the enemy can be expected to destroy everything possible both before and during retirement. A reconnaissance party is sent ahead to determine the condition of the line, the repairs necessary to make it passable, and the location of all materials which can be used in repairing the line. This information is sent back at frequent intervals in fragmentary reports rather than awaiting completion of the reconnaissance, in order that the troops in the rear may push forward the operation of the line as far as possible at an early moment. Special attention should be given to the possibility of contact mines and especially of delayed action mines placed in tunnels, deep fills, bridges, abutments, and other critical points, which would cripple the operation of the line after it had been completely repaired. The location of detour lines which could be constructed rapidly should be investigated. Local sources of ballast material should be investigated in order to avoid as far as possible the bringing up of ballast from the rear.

■ 130. TO DETERMINE CAPACITY OF RAILWAYS.—*a. Main lines.*— The capacity of a single track main line for military purposes should be expressed in terms of the feasible movement of trains per day, thus, "Six 30-car trains per day each way between *X* and *Y*. These trains must not be loaded in excess of 1,500 tons." The capacity of the line as thus expressed is fixed by the speed of operation under the existing physical conditions and characteristics of the line and by the length of the existing passing tracks which fix the number of cars per train. Under military conditions the range of capacity of a line is generally about as follows: A single track line in good condition with a ruling grade of 1 percent and passing tracks at 6- to 10-mile intervals may be depended upon for the passage of 10 trains each way per 24 hours, the maximum length of the trains being fixed by the clear length of the sidings and the maximum tonnage not exceeding 1,500 tons. Where the ruling grade is in excess of 1 percent, the number of trains per day would not necessarily differ from this estimate, since the tonnage of trains can be reduced to meet the demands of increased grade; however, the ton mileage over the line will probably be reduced. On double-track lines the ton mileage is affected by the controlling grade, as in the case of single-track, but the number of trains dispatched over a line per day is usually not so dependent upon conditions of the main line as upon the facilities for dispatching and receiving trains at the terminals.

b. Terminals.—Experience has shown that the capacity of a railroad terminal, in terms of cars passing through it each 24 hours, can be expressed by the total lengths of trackage in either the receiving or classification yards, which are usually of approximately the same size. Therefore, to determine the capacity of a given terminal on reconnaissance, the procedure should be to measure the total length of track in either the receiving or classification yard in feet, divide by the average length of cars to get the approximate car capacity of the yard, and assume that two-thirds this number of cars can be handled through the terminal each 24 hours. The length of the average freight car is 45 feet; passenger coaches and pullmans (or special cars made therefrom for hospital trains) run to as much as 80 feet; the standard military 20-ton cars are all 28 feet long. In each case, car lengths are given as between couplers, and multiples thereof give actual train lengths.

c. Entraining stations, railheads, and depots.—The capacity of entraining points, railheads, and depots should be expressed in terms of loading and unloading possibilities, thus, "The capacity of Station *B* permits the simultaneous loading and unloading of 15 trains of approximately 33 cars each on side tracks without interfering with main-line operations."

■ 131. TO DETERMINE GRADIENT.—A reconnoitering officer should locate the ruling grade by observing the action of a track motor car or locomotive in traversing all rail lines within the territory. If it is impractical to make such observations, it will be necessary for him to decide for himself from observation as to where the ruling grade lies. A quick way of roughly determining the percent of grade is by means of a hand level. Thus, if the observer's height of eye (*H I*) is 5 feet, and the hand level projects his level line of vision to a distance of 250 feet and there intersects the track, the grade is $\frac{5}{250}=\frac{1}{50}$ 2 percent.

■ 132. TO FIND DEGREE OF CURVATURE.—To find the degree of a curve, take a cord 62 feet long, with a knot at the middle, and stretch this cord between the two points on the gage line of the outer rail. With a rule measure the middle ordinate between the cord and the gage line at the knot. The length of this ordinate in inches equals the curvature of the track in degrees.

■ 133. To Determine Capacity of Cars.—The capacities of rolling stock are determined on reconnaissance by inspection of the data usually stenciled on the outside of the cars. The most important data to obtain are the capacity in pounds and in cubic feet. The data should be compiled by car types with numbers in series as far as practicable.

■ 134. To Estimate Capacity of Railway Bridges.—*a. Cooper's rating.*—Many railroads specify Cooper's Standard Loadings as the basis of bridge design. This is a standard loading representing approximately the average locomotives in use, which are usually the critical loads for all bridge design. Figure 77 shows Cooper's E–60 loading. Other loadings are designated as E–50, E–40, etc., these differing from the E–60 type in that the loads are proportionately less, the number and spacing of the axles remaining the same. As there is usually an economic consistency throughout the design of all parts of a bridge, the dimensions of the floor system give a clue to the loading which was probably used in the design of the whole structure. Table XXXV shows the Cooper's E rating of a number of typical railway bridges and the dimensions of the stringers of their floor systems. To estimate the capacity of any existing railway bridge, measure with a foot rule the width and thickness of the lower flange of the stringer or girder at the center, the depth of the stringer, and its length; find in the table the stringer most nearly approximating these dimensions, and read off the corresponding probable E rating of the bridge This result should be modified by the age and condition of the bridge based on judgment or experience before deciding on the actual safe capacity.

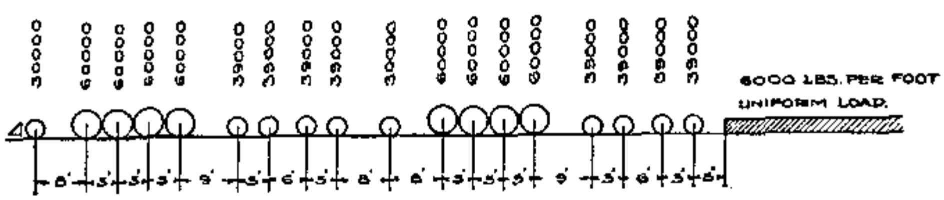


Figure 77.—Cooper's standard E–60 loading.

TABLE XXXV.—*Reconnaissance of railway bridges*

Bridge capacities expressed in Cooper's E rating, as reflected in the dimensions of the stringers of steel truss or open deck girder bridges of various panel lengths

Panel length in feet [1]				10	11	12	13	14	15	16	17	18	19	20	22	24	26	28	30	35
Dimensions of stringers in inches [1]																				
Lower flange		Beam depth	Size of angles																	
Thickness	Width																			
⅜	8⅜	18	4 by 3 by ⅜	E-42	E-41	E-41	E-41	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
⅜	10⅜	24	5 by 3½ by ⅜	-----	E-59	E-48	E-40	E-35	E-31	E-27	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
½	10⅜	30	5 by 3½ by ½	-----	-----	-----	E-61	E-59	E-51	E-46	E-41	E-37	E-33	E-30	E-27	-----	-----	-----	-----	-----
½	12½	30	6 by 4 by ½	-----	-----	-----	-----	-----	E-62	E-56	E-50	E-45	E-41	E-37	E-31	E-26	-----	-----	-----	-----
1	14	36	6 by 4 by ½	-----	-----	-----	-----	-----	-----	-----	E-60	E-58	E-55	E-54	E-51	E-48	E-43	E-39	E-34	E-26
½	12⅜	42	6 by 4 by ½	-----	-----	-----	-----	-----	-----	-----	-----	-----	E-60	E-54	E-45	E-39	E-34	E-30	E-26	-----
1⅛	14	42	6 by 4 by ½	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	E-63	E-60	E-57	E-54	E-51	E-45	-----

Panel length [1]				28	30	35	40	44	50	54	60	64	70	74	80	84	90	94	100	110
Stringer dimensions [1]																				
1⅛	16	42	6 by 6 by ½	E-60	E-54	E-42	E-32	----	----	----	----	----	----	----	----	----	----	----	----	----
1½	16	48	6 by 6 by ¾	----	E-57	E-52	E-47	E-43	E-33	----	----	----	----	----	----	----	----	----	----	----
1	16	48	6 by 6 by ½	E-66	E-59	E-45	E-35	E-30	----	----	----	----	----	----	----	----	----	----	----	----
1⅝	14	54	6 by 4 by ⅝	----	----	E-54	E-43	E-36	E-28	----	----	----	----	----	----	----	----	----	----	----
1¾	14	60	6 by 6 by ½	----	----	----	E-60	E-54	E-43	E-37	E-30	E-27	----	----	----	----	----	----	----	----
1½	14	60	6 by 6 by ⅝	----	----	----	E-57	E-48	E-38	E-33	E-27	----	----	----	----	----	----	----	----	----
2⅛	15	66	6 by 6 by ⅝	----	----	----	----	----	E-57	E-54	E-46	E-41	E-34	E-31	E-26	----	----	----	----	----
2	14	66	6 by 6 by ¾	----	----	----	----	----	E-56	E-48	E-40	E-35	E-30	E-26	----	----	----	----	----	----
2	14	72	6 by 6 by ¾	----	----	----	----	----	E-62	E-54	E-44	E-39	E-32	E-29	E-25	----	----	----	----	----
2½	15½	72	6 by 6 by ¾	----	----	----	----	----	----	----	E-55	E-51	E-43	E-38	E-33	E-28	----	----	----	----
2⅛	14	78	6 by 6 by ¾	----	----	----	----	----	----	E-64	E-52	E-46	E-39	E-35	E-30	----	----	----	----	----
2½	16	84	6 by 6 by ¾	----	----	----	----	----	----	----	----	E-64	E-54	E-49	E-41	E-38	E-33	E-30	----	----
2 11/16	20	96	6 by 6 by ¾	----	----	----	----	----	----	----	----	----	----	----	----	E-59	E-51	E-46	E-41	E-34

For reinforced concrete slab ballast deck plate girder spans reduce the rating given as follows: For spans 10 feet to 19 feet reduce by 8; for spans 20 feet to 45 feet reduce by 10; 50 feet to 75 feet reduce by 12; 75 feet to 120 feet reduce by 14.

[1] For girder bridge without stringers, use the dimensions of the girder itself.

b. Passage of railway artillery.—The military engineer may be called upon to give an opinion of the feasibility of using a given bridge for the passage of railway artillery. Railway artillery mounts have been given corresponding Cooper's E ratings which produce equivalent bridge stresses. Having determined the probable Cooper's rating of the bridge by the above method, a comparison with the equivalent rating of the artillery carriage will be an aid to the judgment. Most bridges are designed with a considerable factor of safety, and for high impact. It is therefore probable that by exercising due caution as to high speed and undue concentration of extremely heavy cars in the train, the bridge will pass artillery carriages of a considerably higher rating than that for which it was designed.

SECTION III

LOCATION AND CONSTRUCTION

■ 135. SCOPE.—The methods of construction of a standard gage railway line in accordance with the refined standards of civil practice are beyond the scope of this manual. The methods described herein are used in the kind of railway construction commonly undertaken in the combat zone, and in the hasty construction of such railway facilities as additional tracks, in yards, at ports, and in military supply installations set up in the communications zone.

■ 136. YARDS.—A yard consists of a number of sidings and spurs usually parallel to each other, although not necessarily parallel to the main track. The tracks must be sufficient in number to facilitate the rapid breaking up of trains, the classification of cars by contents or destination, and the making up of new trains in accordance with new requirements. Yard tracks are divided into groups according to their purpose. A certain number near the main line at one end of the yard are called receiving tracks and constitute the receiving yard where the arriving trains pull in. In convenient proximity are caboose tracks where cabooses are stored when not in trains. A group of repair tracks are convenient to the receiving yard. An engine lead track is provided for moving engines from the receiving yard to the engine terminal, which includes: cinder pit tracks; a coaling station; an engine house; a turntable; wye track or loop for turning engines around; a water station; and engine-ready tracks, where the engines are stored after they have been made ready for service. A train from the receiving yard is pushed slowly over a hump track, the cars being uncoupled at the summit of the hump, handled by brakemen and drifted by gravity into a second group of tracks comprising the classification yard. In yards where there is no hump, the switch engine pushes the cars on to the classification tracks. Cars to be repaired are drifted by gravity into the repair yard. From the classification yard, cars are moved to the forwarding yard, where they are inspected and made ready for movements out of the terminal. Continuous forward progress of cars through the yard is made possible by always permitting movement in at one end and out at the other on each track. In the usual case, a terminal is arranged for classification in but one direction, hence delay and confusion may be saved by double-ending all yard tracks, and by providing a simple, parallel or "empty" yard for movements in the opposite direction. A typical yard layout is illustrated in figure 78, the essential features of which should be provided whenever it is necessary to develop new yards for military purposes.

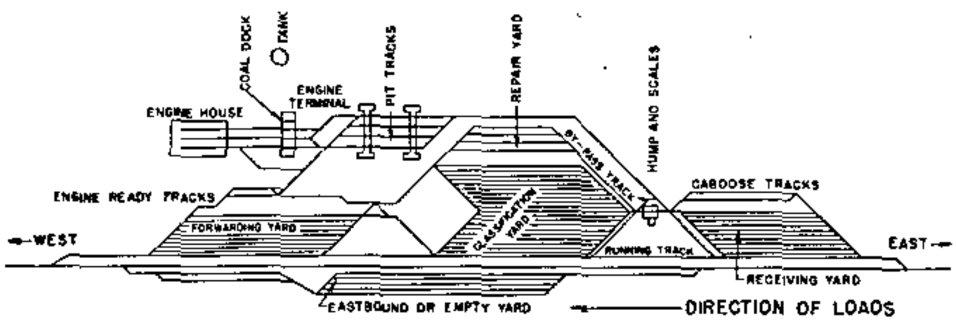


FIGURE 78.—Conventionalized terminal yard layout.

■ 137. TERMINAL FACILITIES.—In spite of the requirement that construction in war be kept to a minimum, it will be necessary to provide adequate facilities at each terminal to insure proper and efficient handling of supplies. Such facilities will include buildings for covered storage, ramps, road and walkways, loading platforms, track turnarounds, and necessary handling equipment such as trucks, elevators, hoists, etc. Most of these, or the materials for their construction, will be derived from civilian sources and must, in many cases, be adapted to requirements.

■ 138. GAGE.—The gage of a track is the distance between the heads of the rails, measured at right angles thereto at a point five-eighths of an inch below the top of the rail. The standard gage of 4 feet 8½ inches is used on about 60 percent of the railway mileage in the world and has been adopted for military railways in the theater of operations. Gages in excess of 5 feet are still used in many places, including Spain, Portugal, Australia, and some countries of South America. In the United States, standard gage is used exclusively, except on some islands of the territory of Hawaii, where a narrower gage of 3 feet 6 inches is found. It is not planned to build narrow gage railways for military purposes in the future, although existing narrow gage railways may have to be used.

■ 139. ROADBED.—*a. Subgrade and ballast.*—The roadbed is the support prepared for the track. It generally consists of the subgrade and the ballast. The ballast affords drainage and distributes the load over the subgrade. Gravel, crushed rock, slag, shells, cinders, and similar porous, hard materials, if available in large quantities, may be used for ballast. In case the subgrade is of such material that drainage is easily effected, or if rains are extremely unlikely over the period that the railroad is to be used, consideration should be given to the feasibility of dispensing with ballast entirely by shaping and dressing the roadbed as indicated in figure 79 ②.

b. Dimensions.—For standard gage single track the roadbed should be 15 feet wide on embankments or 14 feet wide in cuts; for double track, not less than 27 feet should be provided on embankments and 26 feet in cuts. Parallel tracks on tangents are spaced not less than 13 feet center to center; on curves the distance should be increased to maintain equivalent clearances between equipment on adjoining tracks.

c. Clearance.—Figure 80 shows the American Railway Engineering Association standard clearance diagrams for bridges and tunnels. These clearances should be provided whenever possible in military construction and should be departed from only under exceptional circumstances.

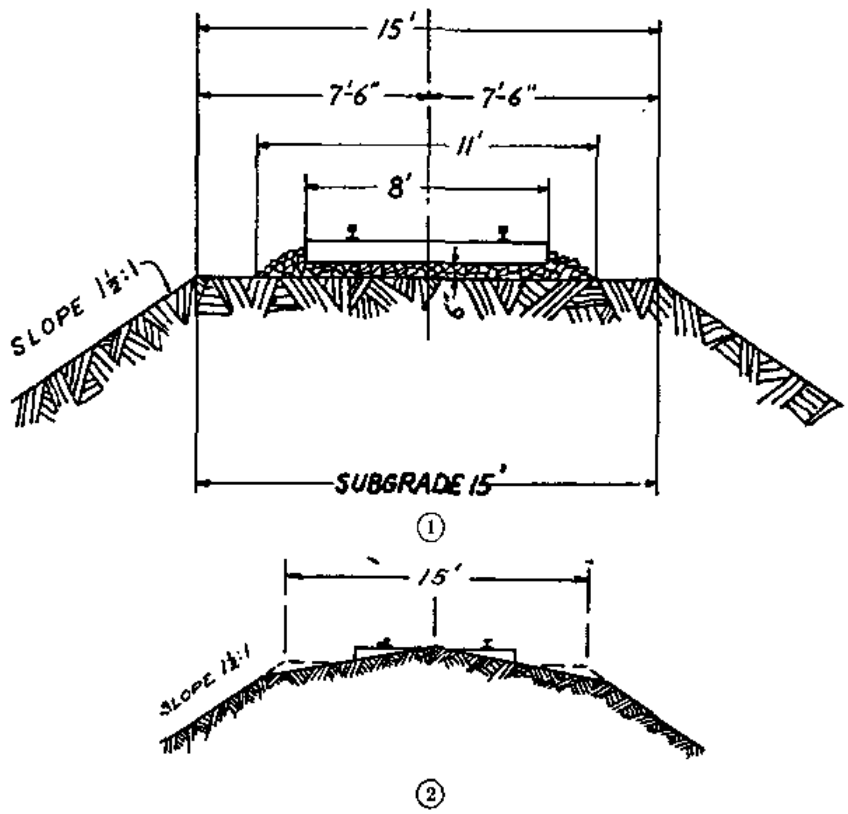


FIGURE 79.—Standard gage roadbed section on embankment.

■ 140. TIES.—The durability of ties depends upon climate; drainage; curvature of the track; volume, weight, and speed of traffic; and a number of other factors relating to the character of the timber from which the ties are made. Since durability is seldom a controlling consideration in military construction, usually it is not important that ideal woods be selected or that special preservation treatments be employed. In fact, almost any available wood will serve the purpose if sawed 8 to 9 feet long, with a rectangular cross section, 6 to 7 inches thick by 8 to 10 inches wide. Hewed ties (recognized by their rounded sides) should have the same cross-sectional areas as sawed ties and faces not less than 6 inches wide. Ties should be spaced 20 inches center to center, as a rule, but if they are wide, it may be necessary to increase this distance to allow 12 inches of clear space between them for tamping.

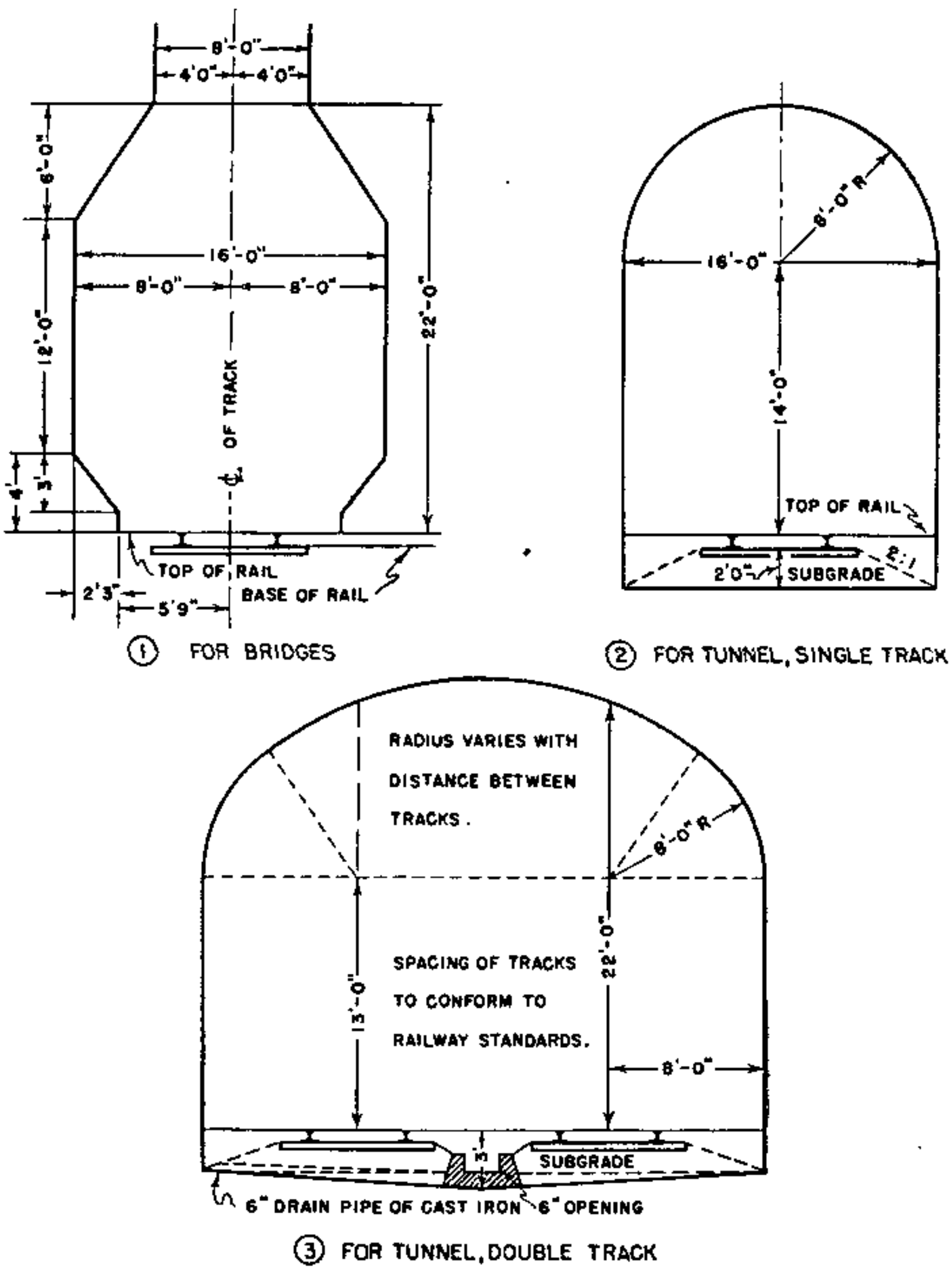


FIGURE 80.—Standard clearance diagrams for bridges and tunnels.

TABLE XXXVI.—*Number of cross ties per mile of travel*

Number per 33-foot rail	Average spacing on centers	Number per mile	Number per 39-foot rail	Average spacing on centers	Number per mile
	Inches			*Inches*	
14	28. 29	2, 240	16	29. 25	2, 166
16	24. 75	2, 560	18	26. 00	2, 437
18	22. 00	2, 880	20	23. 40	2, 708
20	19. 80	3, 200	22	21. 27	2, 979
22	18. 00	3, 520	24	19. 50	3, 249

■ 141. RAILS.—The prevailing form of rail used in this country is that of the standard T-section. The heaviest of these weigh from 120 to 150 pounds per yard, but lesser weight is generally adequate, even on heavy trunk lines. Roads with fairly heavy traffic use 90- to 100-pound rails, especially when grades are heavy and there is much curvature, but light-traffic roads are sometimes laid with 70-pound rails. The standard section adopted for military use is A. S. C. E., 85-pound. The length of rails varies usually from 30 to 39 feet, the majority in present use being 33 feet long. However, some rails as short as 24 feet have been used on occasions, and others as long as 60 feet have been laid and maintained successfully. A 45-foot rail is considered desirable for reducing the number of joints, but is difficult to handle and requires greater allowance for expansion due to temperature. The exact weight of rails in long tons (2,240 lbs.) needed per mile of single track equals $\frac{11}{7}$ times the weight of rail per yard. About 2 percent extra should be allowed for waste in cutting.

■ 142. RAIL FASTENINGS.—*a. Joints.*—A perfect rail joint is one which has the same strength and stiffness as the rails joined by it, but will not interfere with the regular and uniform spacing of ties. A joint is said to be supported when a tie is placed immediately beneath it, and suspended when it falls midway between two neighboring ties. A bridge joint is one which supports the two rail ends between ties upon which the joint itself rests. Angle bars are used extensively as rail joints and are made to fit the rails closely. The great multiplicity of rail designs results in a corresponding variety in the detailed dimensions of the angle bars. Bolt holes are drilled according to any spacing, but care must be taken to see that holes in bars and rails are spaced alike. Figure 81 shows a method of assembling angle bars to form a joint.

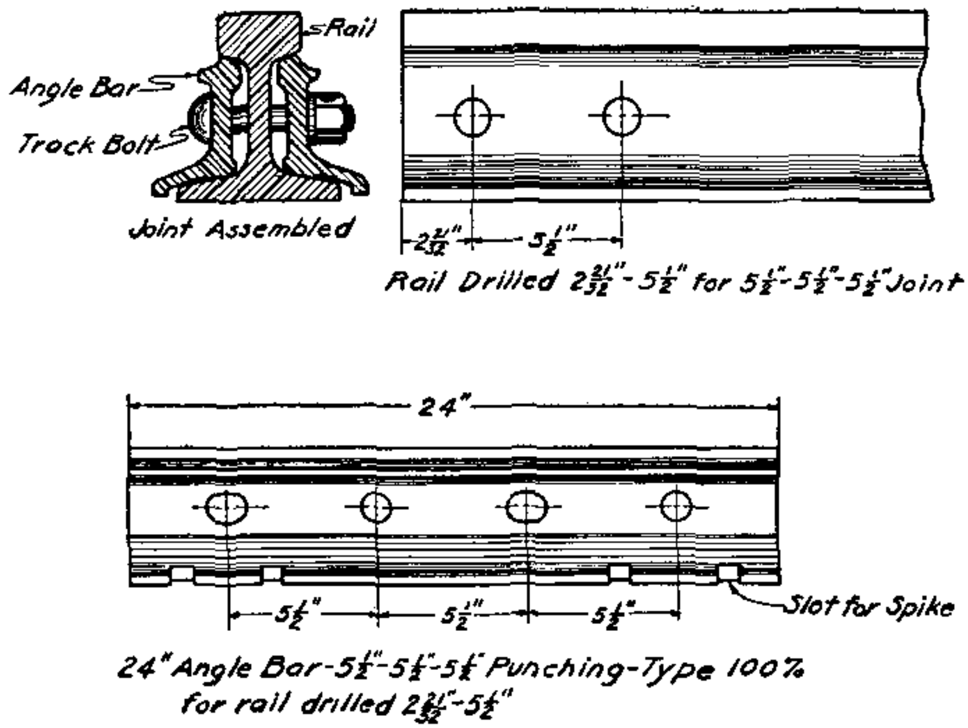
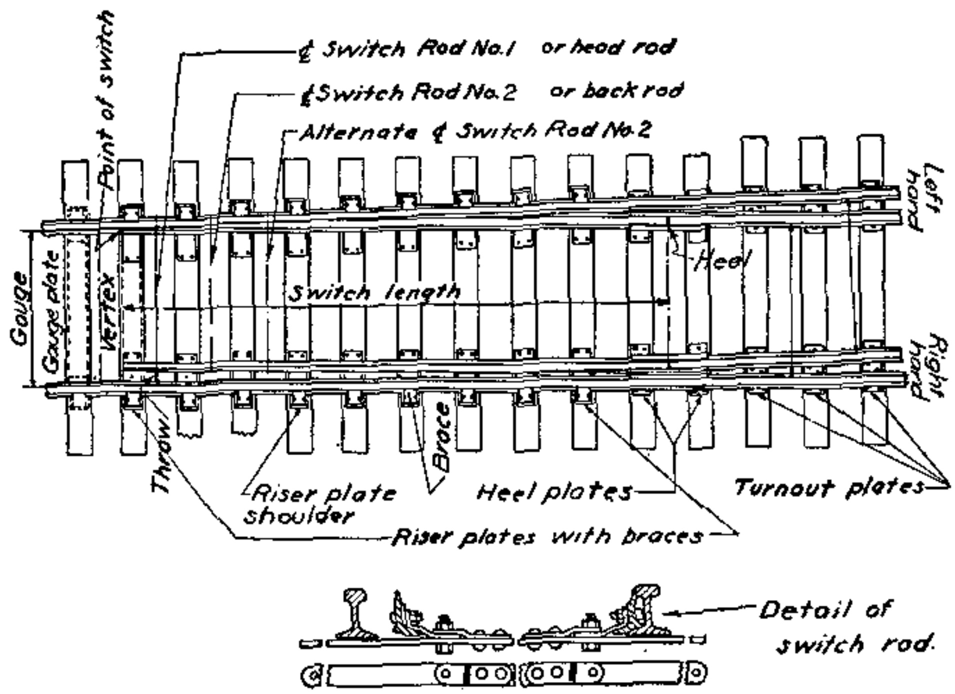


FIGURE 81.—Rail joint.

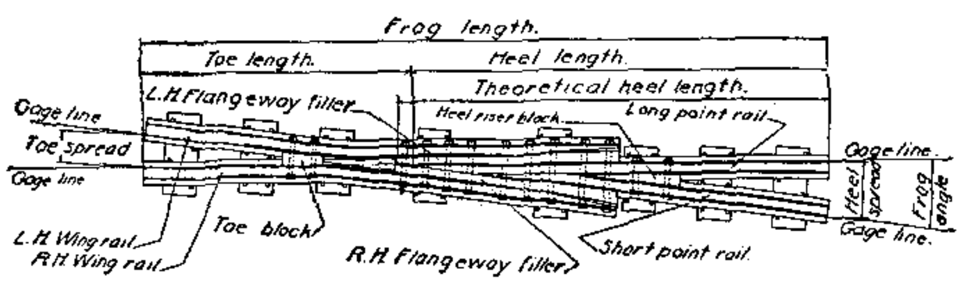
b. Tie plates.—These are flat plates (made from soft or medium steel, or from wrought or malleable iron) which are used to reduce the cutting action by rails on softwood ties and prevent wear in spikes due to vertical vibration of the rail against them. It has been estimated that by the use of tie plates the life of hardwood ties is increased from 1 to 3 years, while that of softwood ties is increased from 3 to 6. Since long life and economy are not normally requirements of military engineering, it follows that the use of tie plates in war will be exceptional.

c. Spikes.—The ordinary spike is made square, nine-sixteenths of an inch in cross section, uniform throughout the greater part of its length. At the lower end it is tapered to a chisel point, while at the top it swells out to form an eccentric head, so designed as to clamp the rail when the spike has been driven against its lower flange. Spikes should be driven vertically into the ties.

■ 143. Switches.—A switch is a device for connecting auxiliary tracks to main tracks or to each other. It con-



① Split switch.



② Frog.

Figure 82.—Nomenclature of split switch and frog.

sists of several parts which are shown and named in figure 82. The purpose of the "frog" is to permit passage of the wheel flanges through the main rail, to which, otherwise, they would be held. Frogs are each provided with two channelways for the flanges to move through and each channel cuts out a parallelogram from the tread areas. Since the wheel tread is always wider than the rail, the wing rails will support the wheel, not only across the space cut out by the channel, but also until the tread has passed the point of the frog to a better bearing surface.

■ 144. SWITCH STANDS.—A switch stand is a mechanism by which a switch is thrown, locked in position, and indicated for the information of those in charge of train movements. It is usually furnished with a lamp and banner signal.

■ 145. GUARDRAILS.—To prevent wheel flanges passing the wrong side of a frog and to save the side of the frog tongue from excessive wear, guardrails are installed at switches, on both main and switch tracks, opposite the frog point. Guardrails are used occasionally on very sharp curves and more frequently on bridges. In the latter case, they are employed along with guard timbers to hold the train on the bridge in case of derailment.

■ 146. CONSTRUCTION OF LINE.—*a. Summary of steps.*—The construction of the roadbed comprises the following steps in order:

(1) A preliminary reconnaissance of the terrain for the selection of the general location of the line.

(2) A survey of the line selected, to obtain topographical data upon which to base the exact location of the line.

(3) A construction survey for setting stakes to give line and grade to the construction party.

(4) The preparation of the subgrade by cuts into, and fills upon the natural ground in order to provide a smooth roadbed for the track.

(5) Unloading and distributing ties along the subgrade.

(6) Spacing ties and placing them in proper alinement.

(7) Unloading and distributing rails.

(8) Unloading and distributing track joint material.

(9) Unloading spikes, bolts, lock nuts, and nuts at rail joint.

(10) Spiking the line rail at uniform measured distance from end of ties to rail.

(11) Lining the opposite rail to gage and spiking rail on tie.

(12) Throwing track to approximate alinement as fixed by line stakes.

(13) Blocking up track to a temporary surface with dirt, stone, or other readily available material preparatory to unloading ballast.

(14) Unloading ballast on track.

(15) Jacking track up and tamping ballast under ties.

(16) Repeating operations in (14) and (15) above, until the required amount of ballast has been inserted to bring the top of rail to the designated grade.

b. *General considerations.*—(1) The construction of the line is preceded by a survey in order to select a line involving the least expenditure of time, the easiest gradients, and the minimum of curvature, cuts, fills, and bridges. If maps are available, showing the characteristics of the country to be traversed, such as contours, rivers, towns, etc., the location of the line can be made directly on the maps, supplemented by personal reconnaissance over the route or routes which appear practicable. If maps are not available, a reconnaissance of the ground is made by the locating engineer, either on foot or by horseback, to enable him to select one or more practicable routes. In making his selection he must bear in mind the limitations of the proposed construction with regard to grades and curves.

(2) The maximum allowable grade will be, in general, the governing factor when deciding which of the possible routes will be chosen for further investigation and construction. The line must be so located as to keep the grade within the adopted limit, which will usually be below 2 percent, although in exceptional cases and for short grades this may be exceeded.

(3) It is usually impracticable to determine definitely what maximum degree of curvature can be used from a mere reconnaissance of a proposed route. However, the locating engineer should satisfy himself that a line can be located with curves not in excess of 10° before adopting any given route.

(4) Natural drainage lines present the easiest and most regular gradients, and in a broad sense it may be said that every railroad location follows lines of drainage. When the head or source of one drainage line is reached, the location crosses the divide of the next. With a few exceptions, drainage lines have gradients not exceeding those permissible for railroad location. The first requisite in considering a railroad location is to get these natural routes clearly in mind before undertaking the reconnaissance. Other things being equal, the shortest route between the initial point and the objective is the line to be followed, but consideration of excessive grades and construction difficulties may outweigh the advantage of shortness.

■ 147. RAILWAY CURVES.—*a. Definitions.*—A line of railway is made up of curved and straight lengths. The former are called curves and the latter tangents. Military railroad curves are usually arcs of circles. They may be either simple, compound, or reverse. A simple curve is a curve with a constant radius. A compound curve is one composed or two or more simple curves of different radii, curving in the same direction and having a common tangent at their point of meeting. A reverse curve is composed of two simple curves, curving in opposite directions and having a common tangent at their point of meeting. The name is also commonly applied to two simple curves, curving in opposite directions, which are joined by a tangent shorter than the usual length of trains running on the line. A transition or easement curve is a compound curve, or spiral, used at the ends of a sharp curve to lead gradually from the tangent to the main curve. For the hasty railway installations coming within the scope of this manual, where high-speed operation is not contemplated, transition curves are not employed.

b. Designation of curves.—A curve may be designated by either its radius, or the angle subtended by a chord of unit length. In the latter case, the angle indicates the *degree of curve,* further designated by the letter D. If C represents the unit chord of a curve with center at O and a radius equal to R, then:

$$R=\frac{\frac{1}{2}C}{\sin\ \frac{1}{2}D}$$

Since 100 feet is taken as the invariable length of a unit chord in the United States, it is possible to obtain an approximate value of R from the following simple, empirical formula:

$$R=\frac{5{,}730}{D}$$

in which D is expressed in degrees and R in feet. The results obtained by this method will be generally correct to a tenth of one percent.

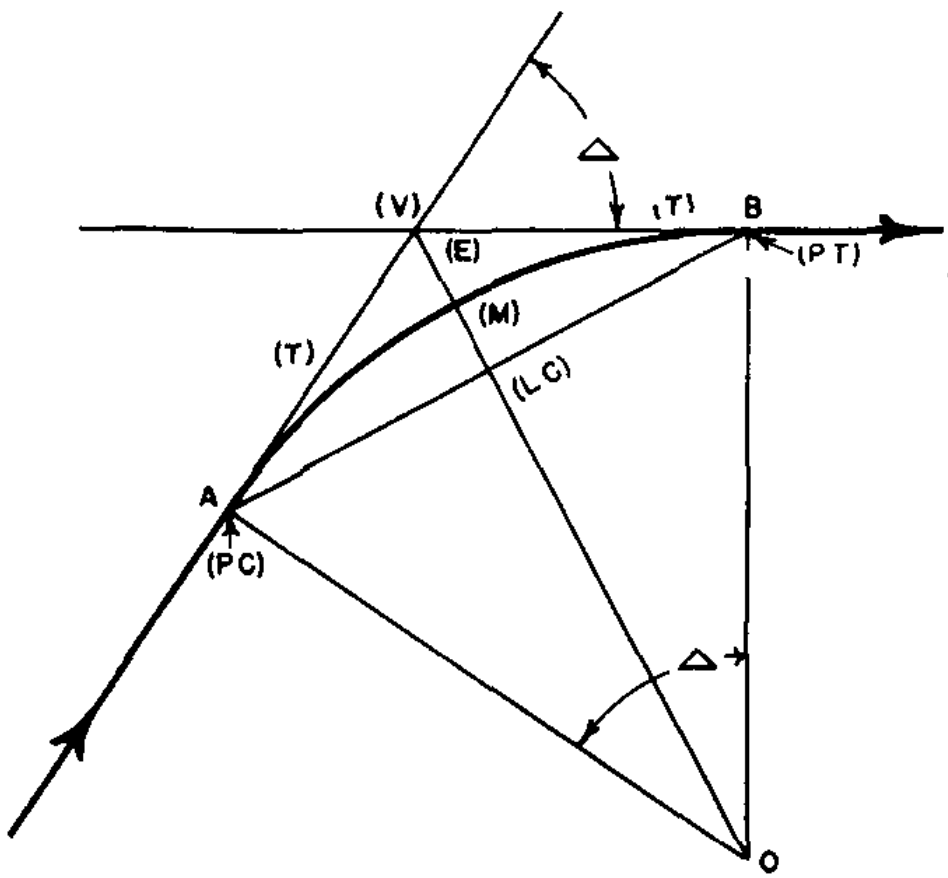


FIGURE 83.—Elements of a curve.

c. Elements of a curve.—Assume a line running along a curve from A to B (fig. 83); then A, the beginning of the curve, is the *point of curve* (PC) and B, the end of the curve, is the *point of tangency* (PT). If tangents are drawn at A and B, their intersection is called the *vertex* (V).

The angle between either tangent and an extension of the other beyond the vertex is equal to the central angle, that which would be designated D if the chord were of unit length. AV and BV, the two equal tangents from the vertex to the PC and PT, are called the *tangent distances* (T). The chord AB is called the *long chord* (LC), and the intercept from the middle of the long chord to the middle of the arc is called the *middle ordinate* (M). The *external distance* (E) is measured by the length of line from the midpoint of the arc to the vertex. By application of the principles of elementary trigonometry the following relations may be derived:

$$T = R \tan \tfrac{1}{2}\Delta$$
$$LC = 2R \sin \tfrac{1}{2}\Delta$$
$$M = R \operatorname{vers} \tfrac{1}{2}\Delta$$
$$E = R \operatorname{exsec} \tfrac{1}{2}\Delta$$

From these equations it is seen that the elements of a curve vary directly as R, and it is also known that R varies nearly inversely as D. If the elements of a 1° curve are now calculated and computed for various central angles (really for various radii), the elements of a curve of D curvature may be closely approximated by dividing by D the corresponding elements of a 1° curve of the same central angle. For small central angles and low degrees of curvature, the errors involved by the approximation are insignificant, and even for larger angles the errors are so small that for military purposes they may be disregarded.

■ 148. PRELIMINARY SURVEY.—*a. General.*—After the reconnaissance of routes that appear most favorable and the determination of the general route to be followed, a preliminary survey is begun. The officer who made the reconnaissance should be in charge of the survey.

b. Organization.—The survey party is organized usually into three groups:

(1) *Transit party*, consisting of one instrumentman, two chainmen, two flagmen, and a number of axemen.

(2) *Level party*, consisting of one levelman and one or two rodmen.

(3) *Topographical party*, consisting of one topographer and two chainmen.

c. *Procedure.*—The locating engineer's place is at the head of the transit party. The head chainman works under his direct supervision. The locating engineer selects the points where it is necessary to change the course and these points are marked by driving hubs (not less than 2 inches in diameter) in the ground. A tack is placed in each hub to indicate the center line.

d. *Stationing.*—The chainmen measure the distance along the center with 100-foot chain, setting stakes every 100 feet which are known as stations, or at intermediate points. The stations are numbered serially from the starting point, beginning with No. 1. The numbers are marked on the face of the stakes with crayon. Station 5+00 is 500 feet and stake 10+55 is 1,055 feet distant from the initial point.

e. *Hubs.*—The head flagman is directed by signals from the transitman in staking out the center line of the survey. He locates the point where the hubs are to be placed and the points where the tacks are to be driven in the hubs. The rear flagman holds a flagpole on the tack in the first hub directly in rear of the transitman to provide a back or rear sight.

f. *Clearing.*—The axemen clear away the brush and obstructions, and work under the direction of the head chainman. One axeman should be detailed to make stakes for the transit party.

g. *Levels.*—The level party establishes bench marks and takes levels along the traverse, taking a reading and recording the elevation at each 100-foot station. The elevation of the starting point, if not definitely known, may be assumed to be 100, 1,000, etc., feet above datum so that all elevations will be positive values. Two or more bench marks should be established in every mile.

h. *Topography.*—The topographic party records data from each side of the center line by stadia readings, obtaining what data are necessary to draw in contour lines and locate features of the landscape over a strip of ground extending to as far as 500 feet on each side where the ground may be used for the final location.

■ 149. PAPER LOCATION.—Upon the map and profile, prepared from notes taken in the preliminary survey, a "paper location" of the proposed railway line is projected, the line of the preliminary survey being shown broken and the located line, solid. The grade elevation for each station on the line is taken from the profile or is obtained by interpolating between the contours. Points having the required elevation are located opposite the corresponding stations of the preliminary survey. These points are inclosed in a circle and marked with the number of the station of the preliminary survey to which they correspond. A line joining the points thus marked is called the grade contour. The paper location is made by selecting a line nearly conforming to the configuration of the ground so as to avoid the necessity of the making of heavy cuts and fills. An approximate profile of the ground along the paper location is then plotted and approximate grades are established, particular attention being paid to the balance of cuts and fills where possible.

■ 150. FIELD LOCATION.—One or more field parties may be organized in accordance with the urgency of the situation. If only one party is organized it establishes the first tangent in the field by scaling from the paper location the distances from the original traverse to this tangent at convenient points and establishing base points. It then establishes the second tangent in the same manner, produces these two tangents to a common point of intersection and measures the central angle. With this point of intersection and the degree of curvature shown on the paper location, the party then establishes the tangent distance, which is measured back from the point of intersection to the point of curve and ahead from the point of intersection to the point of tangent. The stationing is established on the tangent up to this curve, the correct station of the point of curve is then determined, the instrument set up on this point of curve, and the curve laid out. The party then proceeds with the stationing on the second tangent until it reaches approximately the point of curve of the next curve. If two or more parties are sent out in the field to establish the line, the line is divided into several sections according to the number of parties and each party begins with the establishing of the first tangent within its section and proceeds as described above, with this difference—it does not establish the stationing on the line but merely determines by stakes the points of curve and points of tangent, so that the party following can proceed without interruption. In other words, the second, third, or fourth parties will only lay out the line, chopping down trees and clearing brush where necessary so as to have a clear sight for establishing the tangents and points of curve. The chaining is carried on by party No. 1, which will, upon arriving at the section of party No. 2 or 3, lay out the curves as found necessary. Where two parties join and where revisions have been necessary in the paper location, a modification will have to be made in the curve, joining the tangents of the two adjacent sections, but the degree of curvature on the paper location should be adhered to if possible. After the location has been definitely established in the field and stakes placed every 100 feet on the line, a leveling party is organized which will take levels at every one of these stakes, establishing bench marks as they go along. This leveling party should follow immediately after party No. 1 as described elsewhere so as not to delay this work.

■ 151. CONSTRUCTION STAKES.—In order to proceed with the grading, grading stakes are set out, being placed at the top of a slope when in a cut and at the foot of a slope when on a fill. The construction party grades up to or down from these stakes. No further instrumental work is necessary except for the definite location of culverts, abutments, or structures of this kind. It is advisable to place stakes at 50-foot intervals on sharp curves. For curves up to 6° it is not necessary to place stakes closer than 100 feet apart for military railroads.

■ 152. PREPARATION OF SUBGRADE.—*a. Methods.*—In the preparation of the subgrade, use may be made of any or all of the following equipment: Power shovels; large capacity earth moving equipment (carry-alls) of the wheeled-scraper type drawn by heavy duty tractors; bulldozers; small capacity wheel and drag scrapers drawn by light tractors or animals; hand tools; dump cars; trucks; wagons; and wheelbarrows. When available the shovels, large capacity earth moving equipment drawn by heavy duty tractors, dump cars, trucks, and wagons are used when the work consists of heavy cuts and fills involving movement of large quantities of material over considerable distances. Bulldozers are used in almost any type of grading operation, being especially useful for cuts and fills in close proximity to each other, and for side hill cuts. The small capacity scrapers are best used in light cuts and fills, not exceeding depths of about 10 feet, and where the adjacent cuts and fills approximately balance, or the material can be conveniently wasted within a reasonable distance. Wheelbarrows are used in connection with shallow cuts and fills by hand labor, small quantities of borrow, and work in soft, marshy ground.

b. Grading for new construction.—An excellent method for new construction of the roadbed for standard gage lines is by the use of tractor-tread power shovels using light, standard gage, air-operated, side-dump cars of 16 or 20 yards' capacity, and light, standard gage, steam or gasoline donkey engines to move the earth from cut to fill. Ties and rail for a light construction track are brought up by wagons or trucks. Where the roadbed is to lie on a side-hill slope, a pioneer grade, just wide enough for the construction track, should be made by working the shovel and casting the material for the length of the entire side-hill section. The shovel is then brought back to the initial point and the work of widening the grade is started. As a section of construction track is laid on the pioneer grade, the dump cars are moved up to the shovel, and the cars are loaded and moved to a point where material is needed. Where through-cut sections are necessary, the shovel is started at grade at the point where the cut begins. Where fills are necessary, very light trestles are constructed, from which the cars are dumped. The work can be carried out with narrow gage equipment with equal facility, but even in this case time is saved in the final con-

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struction if full-sized ties for the standard gage track are used for the narrow gage construction track.

c. *Grading of captured lines.*—Grading of captured lines consists of repairing the roadbed in spots where breaks have been caused by enemy demolitions. Earth is obtained from nearest sources, either by widening cuts or by taking it from side borrows.

■ 153. TRACK LAYING.—*a. General.*—Laying the track upon the finished subgrade may be accomplished in several ways. One method is by extending the track with materials supplied over the line by a work train which advances as the track is laid. Where good highways exist, motor trucks can be employed to distribute track material, except ballast, in dumps at intervals of from ½ to 1 mile apart along the line. Track laying can then start from several points simultaneously, materials being distributed by teams or trucks along the grade. Care must be taken in this case to fill all ruts made in the subgrade by the vehicles before the track is laid. Where the track is to be laid parallel to an existing track, the problem is simplified by the possibility of dumping ballast upon the prepared subgrade from the existing tracks. The new track can then be laid directly upon the ballast

b. Organization.—Where the subgrade has been completely prepared, ties, rails and accessories, and ballast are brought to the end of the existing rail on cars pushed ahead of a locomotive. On the first three flat cars are stacked about 1,500 ties. These cars are followed by two flat cars loaded with about 150 rails, followed by another flat car loaded with splice material, tie plates, and spikes, followed by still another carrying all necessary tools for the working parties. The above quantities of material are sufficient to lay about one-half mile of single track. Ballast is brought up in a separate train. The organization and duties of the track-laying party may be as follows:

TABLE XXXVII.—*Typical organization for track-laying party for laying track with work-train service*

Duties	Superintendent	Foreman	Subforeman	Squad leader	Workers	Teams or trucks
General supervision	1	----	----	----	----	----
Unloading ties	----	----	----	1	7	----
Carrying and placing ties	----	----	----	2	14	----
Unloading and hauling rails	----	----	1	1	7	1
Handling and placing splice bars, tie plates, spikes, bolts, etc., ready for use	----	1	----	2	14	----
Laying rail, temporarily bolting splice bars, spiking about every other tie ahead of work train	----	----	1	4	28	----
Full bolting and spiking behind work train	----	----	1	2	14	----
Unloading ballast from ballast train	----	----	----	2	14	----
Bringing rails to a proper surface and alinement. Tamping ties	----	1	1	6	42	----
Checking up and correcting any errors in grade, surface, alinement, spiking, bolting, etc	----	----	----	1	7	----
Total	1	2	4	21	147	1

c. Alinement.—The general alinement of the track is marked by stakes set on the center line of the proposed track at intervals of 100 feet. The exact center line is marked by tacks in the head of the stakes. The center stakes should be left at least 1 foot above the surface of the finished subgrade in order that reference may be had to them even after the track has been raised on ballast. One side of the track is referred to as the line side. As cross ties vary several inches in length, a tolerance of 3 inches being allowed in common practice, it is customary to make the ends of the ties line up on one side of the track. Thus, on a track running generally east and west the south rail may be designated as the line rail. The opposite rail, laid at gage distance from the line rail, is called the gage rail. On curves, the line side is always on the inside of the curve regardless of direction. On double-track lines the outside rail on each track is the line side, whether on tangent or curve. The ties are installed so that their ends on the line side will be a fixed distance from the web of the line rail. This distance, which provides equal rail bearing on the ends of ties, is generally 22½ inches from the web of the rail to the end of the tie. The spikers cut a notch in the handle of their spike mauls 22½ inches from the end, and a tie should be shifted under the rail before spiking so that the end comes even with this notch when the end of the maul handle is placed against the web of the rail.

d. Tie plates.—When insufficient tie plates for all ties are available, preference should be given to the sharpest curves. The shoulder of the tie plate is placed on the outside of the rail, fitting the outside base of the rail snugly. In hasty military construction tie plates are not essential for new construction and may be omitted if necessary. However, if they can be secured they should be used.

e. Joints.—On curves and tangents of less than 500 feet in length, the rail is laid with broken joints; that is, a joint on the gage rail is located about opposite the middle of the length of line rail. Short rails are introduced as necessary on the inside of long curves to produce this result. On tangents of a greater length than 500 feet, the joints should be square; that is, the joints in each rail should be directly opposite each other, since this aids in maintaining the cross level of the track. Before the rail is spiked to the ties at the joints, all bolts in the joints should be fully tightened in order to prevent kinking of the rail. Lock washers should be used on each bolt.

f. Allowance for expansion.—Metal shims are used between the ends of the rails to provide a space for expansion of the rail during increases of temperature. The thickness of the shim to use varies with the temperature of the rail at the time of laying, as shown by a thermometer placed near the rail, in accordance with the following table. Shims are removed after side plates have been bolted.

TABLE XXXVIII.—*Temperature expansion for laying rails*

[Based on 33-foot rail lengths]

Temperature (°F.)	Allowance
	Inch
0 to 25	¼
25 to 50	3/16
50 to 75	⅛
75 to 100	1/16

For military purposes these requirements are not necessary as the rail temperature and the approximate spacings are estimated. Except on long tangents the effect of expansion is of small importance compared to other details.

g. Spiking.—In spiking the rail to the ties, the outside spike should be set ahead of the inside spike to prevent the slewing of the tie (see fig. 84). The line-side rail is spiked first. In spiking the opposite or gage rail the track gage is used at about every fourth tie. The intermediate spikes can then be driven without using the gage.

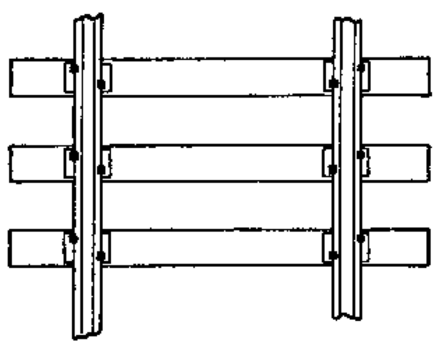


FIGURE 84.—Method of setting spikes.

h. Ballasting.—Ballast is usually placed in two operations or raises. The material is dumped on top of the track which is then raised by jacks to a little below the desired grade. The ballast is then tamped under the ties for a distance of at least 1 foot in both directions from each rail. After the track has been allowed to settle for a few days under work-train traffic, a second dumping of ballast is made, the track is raised and jacked up to the desired grade, and the ties are

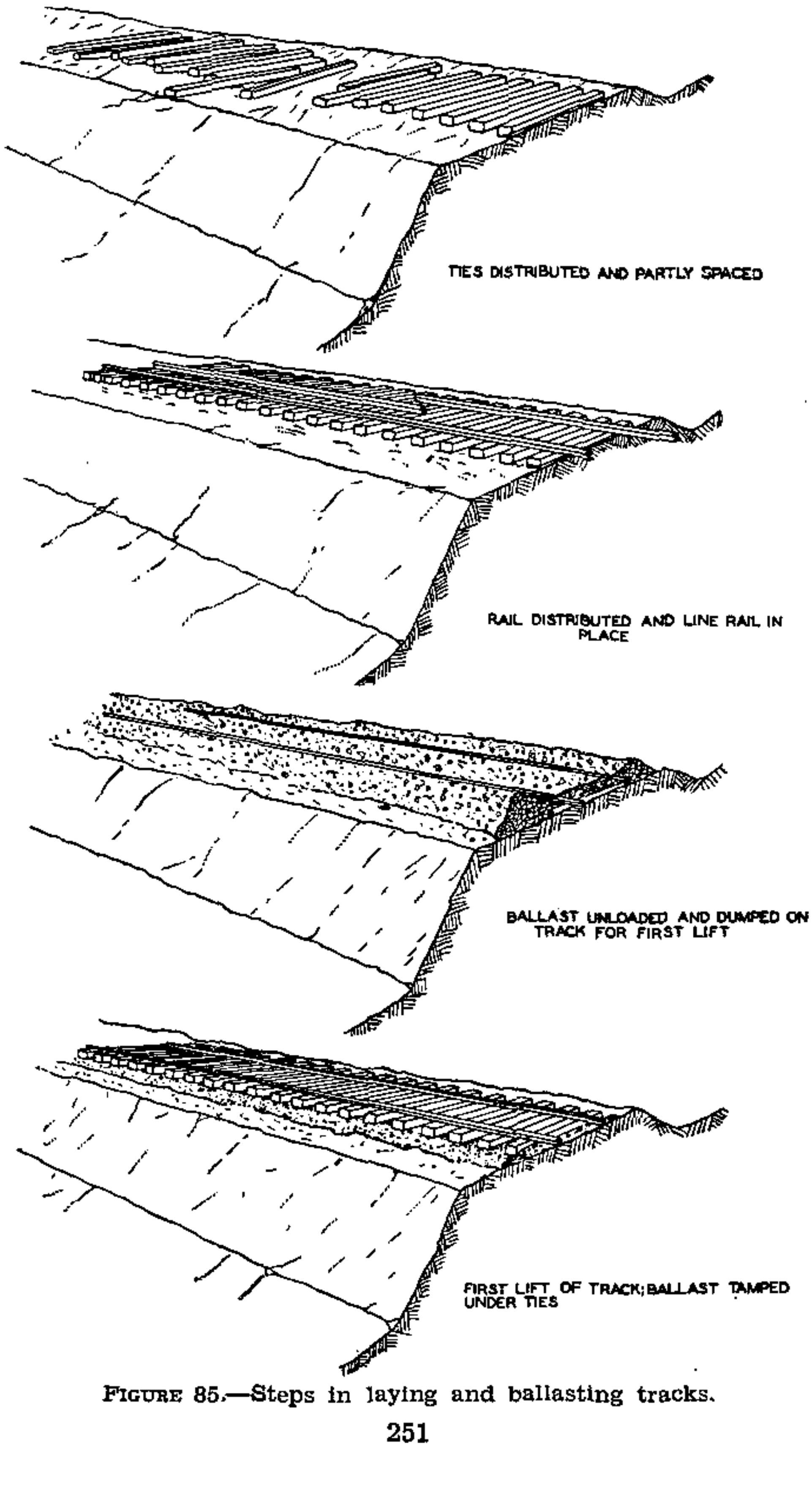


FIGURE 85.—Steps in laying and ballasting tracks.

again tamped for a distance of 1 foot on each side of each rail. Jacks should not be applied directly under the joints, as this is likely to break the splice bars. For amount of ballast, see table XXXIX.

i. Lining.—In lining track to the center stakes, 8 or 10 men with lining bars, working under the direction of a foreman, are usually sufficient. The foreman measures from a center stake the distance that the track will have to be thrown. The men place their lining bars under the rail and by heaving together move the track to the proper location. Another center stake, preferably 200 or 300 feet distant, is then selected and same operation repeated. The use of more than 10 or 12 men with lining bars is usually disadvantageous because of a tendency to throw the track too far at one time.

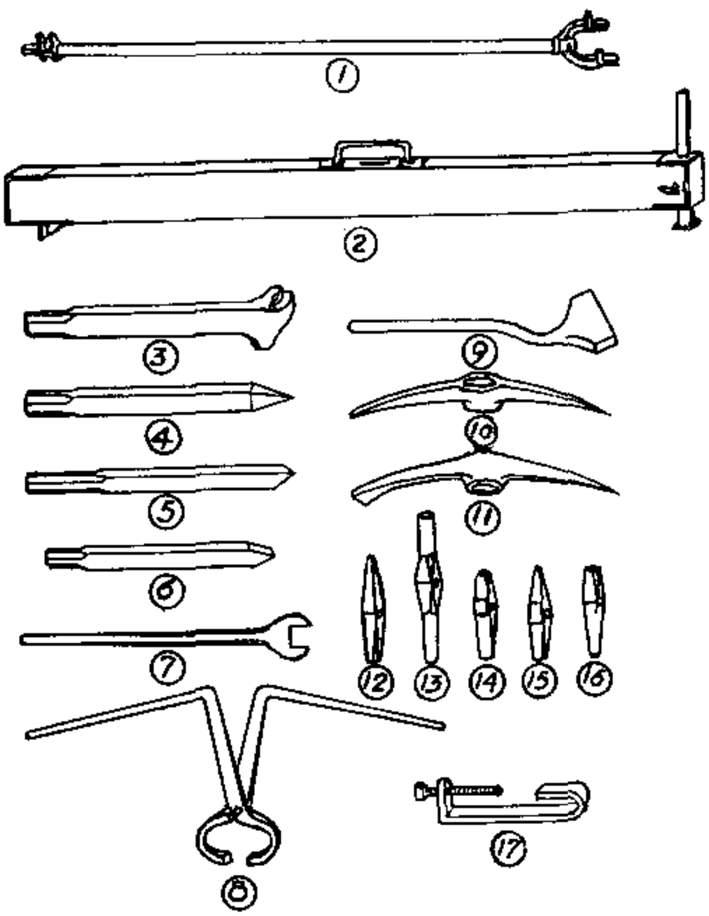
TABLE XXXIX.—*Standard gage railway—cubic yards of ballast per mile of track*

[Ties 6 by 8 inches by 8 feet, spaced 20 inches center to center; ballast dressed even with the tops of the ties and sloping from the ends of the ties 1 on 4]

Inches of ballast under tie	Cubic yards of ballast per mile
4	1, 529
5	1, 779
6	2, 032
7	2, 295
8	2. 577
9	2, 863
10	3, 137

TABLE XI.—*Standard gage railway—materials for 1 mile of single track*

Weight per yard (pounds)	Rail gross tons	90 percent—33 feet, 10 percent—28 feet			Spikes (4 per tie)						
		Splice bars (pairs)	Bolts		Size	Ties spaced 18 inches center to center, 22 per 33-foot rail, 3,520 per mile		Ties spaced 20 inches center to center, 20 per 33-foot rail, 3,167 per mile		Ties spaced 22 inches center to center, 18 per 33-foot rail, 2,880 per mile	
			Average size	Approximate number of kegs		Pieces	Kegs	Pieces	Kegs	Pieces	Kegs
				(4 per joint)							
50	78.57	325	¾ by 3	4.6	9/16 by 5½	14,080	42.66	12,672	38.38	11,520	34.91
55	86.43	325	¾ by 3¼	4.7	9/16 by 5½	14,080	42.66	12,672	38.38	11,520	34.91
60	94.29	325	¾ by 3½	4.9	9/16 by 5½	14,080	42.66	12,672	38.38	11,520	34.91
70	110.00	325	¾ by 4	5.2	9/16 by 5½	14,080	42.60	12,672	38.83	11,520	34.91
75	117.86	325	⅞ by 4	7.7	9/16 by 5½	14,080	42.66	12,672	38.38	11,520	34.91
80	125.71	325	⅞ by 4¼	7.9	9/16 by 5½	14,080	42.66	12,672	38.38	11,520	34.91
85	133.57	325	⅞ by 4½	8.2	9/16 by 5½	14,080	42.66	12,672	38.38	11,520	34.91
90	141.43	325	1 by 4½	10.8	9/16 by 5½	14,080	42.66	12,672	38.38	1,520	34.91
100	157.14	325	1 by 4¾	11.2	9/16 by 5½	14,080	42.66	12,672	38.38	11,520	34.91
105	165.45	325	1 by 4¾	11.2	9/16 by 5½	14,080	42.66	12,672	38.38	11,520	34.91
				(6 per joint)							
110	172.86	325	1 by 5	17.4	⅝ by 6	14,080	55.21	12,672	49.68	11,520	45.17
120	188.57	325	1 1/16 by 5	19.7	⅝ by 6	14,080	55.21	12,672	49.68	11,520	45.17
130	204.29	325	1⅛ by 5½	21.9	⅝ by 6	14,080	55.21	12,672	49.68	11,520	45.17
140	220.00	325	1 3/16 by 5½	23.2	⅝ by 6	14,080	55.21	12,672	49.68	11,520	45.17



(1) Track gage.
(2) Track level.
(3) Claw bar.
(4) Lining bar.
(5) Crowbar (pinch point).
(6) Crowbar (wedge point).
(7) Track wrench.
(8) Rail tongs.
(9) Tamping bar.
(10) Pickaxe (clay pick).
(11) Tamping pick.
(12) Spike maul.
(13) Spike maul (Pittsburgh pattern).
(14) Track chisel.
(15) Track punch.
(16) Track punch (round point).
(17) Rail clamp.

FIGURE 86.—Track tools.

j. Surfacing.—Surfacing is the act of giving the track evenness or smoothness over short distances. In surfacing the track, jacks are worked in pairs opposite each other. It is necessary to dig jack holes in the ballast to allow the foot of the jack to go under the rail at intervals of from 10 to 20 feet. The jacks should always be set on the outside of the rail, because it is easier to remove jacks so set, and men working on opposite jacks do not interfere with each other. The foreman in charge of surfacing raises one rail to the proper elevation by eye and brings the opposite rail up to the proper elevation by use of the track level; the ties are then well tamped.

k. Dressing.—Completely ballasted track should be dressed so that the ballast is even with the tops of the ties from end to end, then to a slope of 1 on 4 to the subgrade. With the poorer qualities of ballast that do not drain well, it is essential that the lower surfaces of the ends of the ties be kept above the surface of the ballast, or churning will take place. Where such ballast is used, the ballast between the ties should be sloped from the rail to the lower edge of the tie. When rock ballast is not used, track is surfaced with dirt in a similar manner, adding a rounded crown between the rails to insure drainage.

■ 154. CURVING RAILS.—The curving of rail with a rail bender is necessary only in track of very sharp curvature, not likely to be found on standard gage military railways. For the curves used on military railways, the rails are sufficiently flexible so that the curving can be easily accomplished by spiking the rail to the ties, and lining to the curve, as described.

■ 155. CUTTING RAIL.—The best method for cutting heavy rail sections in the field is as follows:

a. Mark the rail with a track chisel around its entire circumference at the point where it is desired to break it.

b. Set the rail upright on the ties in a track with one end in contact with a running rail.

c. Set two spikes firmly to fasten the piece of rail to a tie at the point marked.

d. Eight or ten men using lining bars then line the free end of the rail away from the running rail, creating as great a strain at the point marked as possible.

e. A blow with a hammer on the head of the rail at the marked section will then cause it to break.

To cut a piece of rail of 3 feet or less, it is necessary to mark the entire circumference of the rail very deeply with a track chisel. Generally, after the entire circumference has been marked to a depth of from one-fourth to three-eighths of an inch, a few blows of a hammer will cause the piece to drop off. Rails can also be cut with an oxyacetylene torch or with a hack saw.

■ 156. SUPERELEVATION OF OUTER RAIL.—*a. Forces to be overcome.*—When a train runs on a curve there are two forces acting to crowd the wheel flanges against the outer rail, namely, centrifugal force and the tendency of the stiff trucks to run straight. The former varies as the square of the speed; the latter is constant for all speeds. If the train is stretched so that a tension exists on all drawbars, the pull of the locomotive works against these two forces and tends to draw the trucks to the inner rail, but this effect is small, variable, and negligible.

b. Applicatory rule.—To reduce pressure on the outer rail on curves, it is elevated above the inner rail by a certain amount. For speeds not over 35 m. p. h., a safe rule for standard gage is to elevate three-fourths inch per degree of curvature, attaining this elevation gradually on the tangent and reaching full elevation at the point of maximum curve. The maximum superelevation should not exceed 7½ inches. This rule is modified or not applied on curves in special situations where all traffic must run at low speed, as at important stations, crossings, in yards, etc. It is not used on switches and yard tracks which are adapted to low speed only. Superelevation should be based on the most frequent velocities, with faster trains being slowed on sharp curves.

■ 157. PRACTICAL INSTALLATION OF TURNOUT.—*a. Required items.*—Many types of switch material are in use on commercial railways, each railway having its own standards, but the essential items for installing a turnout are as follows, the weight and section of rail corresponding to that in the track:

(1) One set of switch ties, according to the frog number. A turnout may be installed without switch ties by interlacing track ties.

(2) One switch, complete, consisting of 2 switch points, right and left, with lugs, and approximately 2 rods and 14 plates and braces, depending on the type. In some types of material the rods are adjustable.

(3) One frog. If a spring frog, right or left hand must be specified, depending on whether the turnout is to the right or left.

(4) Two guardrails. Guardrail clamps, one for each guardrail, are desirable but not essential. The guardrail may be bolted to the track rail, but will serve without clamps or bolts if properly spiked and braced.

(5) One switch stand, with throw to operate switch.

(6) One connecting rod, adjustable, from switch stand to head rod.

(7) Necessary rail, angle bars, and track fastenings, depending on the length of the lead.

(8) Foot guards are desirable but not essential for the heel, toe, and wing rails of frogs, ends of guardrails, and heels of switch points. They may be of wood or metal and may be improvised. The frog number is the ratio of the distance from the actual point of the frog (of any section on the tongue) divided by the width of the tongue at that section. If a knife or pencil is used that equals the tongue width, and the theoretical point is eight times this width distant, the frog is No. 8. Only point switches should be used; they have one main rail and one scratch rail uncut and immovable. The other main and switch rails intersect at a frog.

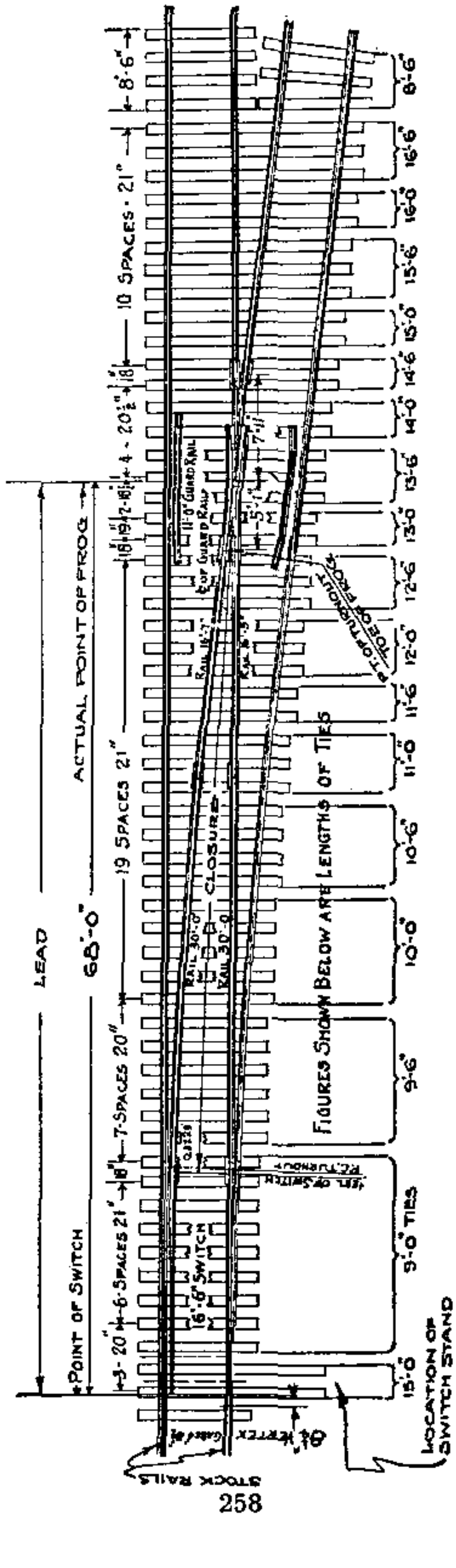


FIGURE 87.—Typical layout of No. 8 turnout standard gage railway.

TABLE XLI.—*Typical turnouts for standard gage railway*

	Frog number		
	7	8	10
Frog angle	8° 10′	7° 09′ 10″	5° 43′ 29″
Frog length	12′ 2″	13′ 0″	16′ 6″
Switch length	15′ 0°	16′ 6″	16′ 6″
Switch angle	1° 40′	1° 44′ 11′	1° 44′ 11″
Lead	64′ 6″	68′ 0′	78′ 9″
Straight closure	45′ 0″	46′ 5″	55′ 10″
Curved closure	45′ 2 15/16″	46′ 7″	56′ 0″
Point of switch to heel of frog	72′ 2″	75′ 11″	88′ 10″
Point of switch to end of switch ties	90′±	93′ 0″	114′ 6″
Point of switch to 12′ clearance point	121′±	127′ 3″	151′ 1″±
Point of switch to point of switch on ladder tracks 13 feet center to center	91′ 6⅛″	104′ 5¼″	130′ 4″
Point of switch to point of switch, required minimum	77′±	81′±	94′±

NOTE.—The meaning of the terms used in this table will be clear from an examination of figure 87.

b. Frogs for turnouts.—Assuming that the main line is in existence and it is desired to install a turnout, it is first necessary to determine the desired location of point of frog and the number of frog to be used. Table XLI gives the data for turnouts with the frog numbers in most common use. In cases in which the frogs available are not of any of the numbers given, the same data can be determined by measuring an existing turnout which has a frog of the same number as the one to be used. In general, on commercial railways in the United States, No. 7 or No. 8 frogs are used in yard tracks, No. 10 frogs in mainline turnouts, and No. 16 or No. 20 frogs at the ends of double track. For the purpose of simplifying the problem of supply, it has been decided that engineer depots will be prepared to furnish only No. 8 frogs. These are suitable for general use. Problems which may be encountered in yard revision or in locating new switches in complicated existing track layouts may be solved on paper by plotting the existing tracks on a scale of one-eighth inch equals 1 foot, or greater, and then testing various plans. Such designs will normally be made by experienced railroad personnel; the average engineer need only know how to install single simple switches.

c. Curvature.—When a switch is on the inside of a curve, the degree of curvature of the switch is approximately its normal degree plus the degree of curvature of the main line; if outside, the degree of curvature of the switch is the difference of these two. Thus, if a No. 8 frog calling for a curve of $11\frac{3}{4}°$ is installed on the inside of an $8\frac{1}{4}°$ curve, the curvature through the turnout will be $11\frac{3}{4}+8\frac{1}{4}=20°$. Safety against derailment and economy in maintenance require that switches be located so that the curvature of the turnout will not be in excess of 16°. Switches should always be located on tangents, if possible, to simplify switch layouts.

d. Location of switch point.—After the location and number of the frog have been determined, a stake in the center of the track or mark on the rail should be placed to locate the point of switch. The lead distance is measured from this point to determine the location of the switch point.

e. Rail cutting.—Measurements should be taken to determine the number and length of the rails to be cut. Joints must not fall in the continuous rails between the point and heel of the switch points or between the ends of the guard rails. Rail cuts should be made before commencing to install the switch.

f. Subsequent procedure.—(1) Pull all spikes from every other cross tie throughout the length to be occupied by switch ties and remove the ballast from around these unspiked cross ties.

(2) Set track jacks under the rail and loosen the track by jacking it up very slightly.

(3) Withdraw the loose ties and substitute switch ties of the proper lengths.

(4) Remove the remainder of the cross ties and substitute switch ties in a similar manner.

(5) Set the frog. This can be done in 15 minutes by a party of 12 experienced men and consists merely of taking out the rail where the frog is to be located, setting the frog into place, spiking it up to gage and making the connection with the proper length of cut rail, and installing a guard rail opposite the frog.

(6) Assemble the inside lead rail, join it to the frog and the switch point, and spike it up so as to allow 6¼ inches clearance between the heads of the rail at the heel of the switch, leaving the rail to be shifted back and forth between the heel of the switch and the frog.

(7) Line the lead rail by eye and spike it.

(8) Unspike and line out the main line rail on the turnout side.

(9) Fit the slide plates beneath it and place the switch point against it. When the main line rail (stock rail) is lined to the proper point, the gage will just fit from the opposite main line rail to the gage line of the switch point. Both the switch point and the stock rail should be spiked at this time and a rail bender should be applied so as to produce a slight kink in the stock rail 8¼ inches ahead of the switch point so that the switch point may fit against the stock rail without creating a line kink.

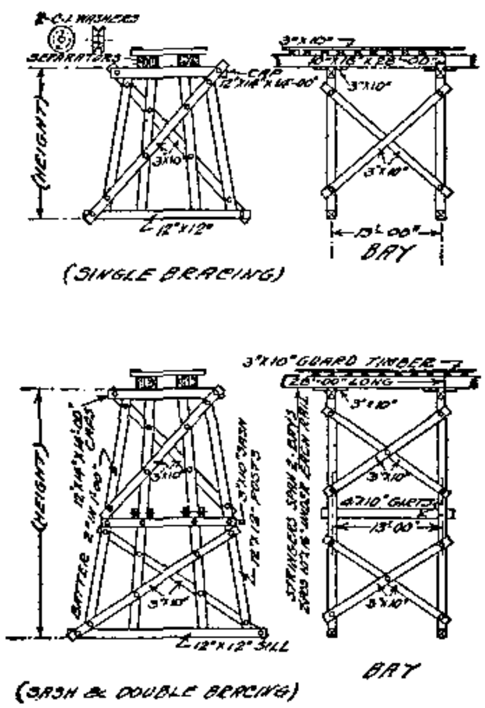
(10) Lay the outside lead rail to connect with the stock rail at the proper gage distance from the inside lead rail.

(11) Install the guardrail opposite the frog on the outside lead rail. It is important that the gage fit exactly from the point of frog to the outside lead rail and that the guardrail provide a flangeway of 1¾ inches.

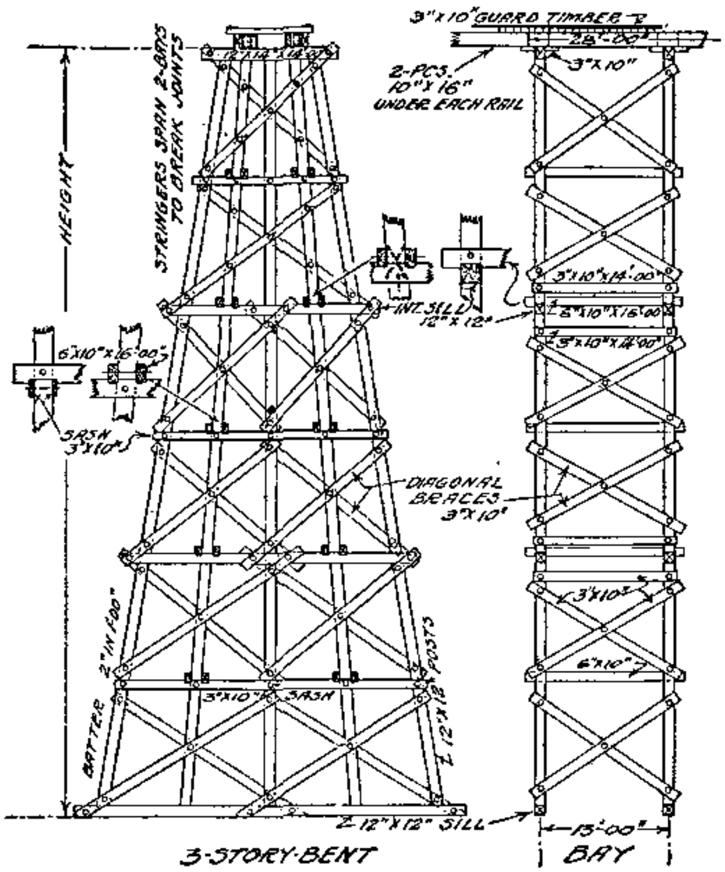
g. Installation of switch points and switch stands.—The main line side switch point may now be installed, the head and back rods applied, switch stand set up on the turnout side of the main line, and the connecting rod installed. It will always be necessary to adjust the head and back rods in such a manner that each switch point will fit snugly when thrown against the stock rails.

h. Time of installation.—An experienced foreman and 12 men can install a turnout in an existing track in 2 working days of 8 hours each, provided material is assembled and ready for installation. Where a new switch is installed, incident to the construction of the main line itself, a turnout can be completely installed and ballasted in 8 hours.

■ 158. BRIDGES.—*a. General.*—A discussion of the design and construction of bridges is given in chapter 2. Figure 88 shows the general form of construction of a high trestle



① 1-story-bent



② 3-story-bent

FIGURE 88.—Timber trestle bridges for standard gage railways.

railroad bridge. Pile bents are in order when driving equipment is available and foundations are suitable; timber cribs may be employed when heights are less than about 10 feet and adequate material is at hand. Figure 89 shows a floor system adaptable to both trestle and pile structures. A railroad bridge should not be built on an incline or a curve if

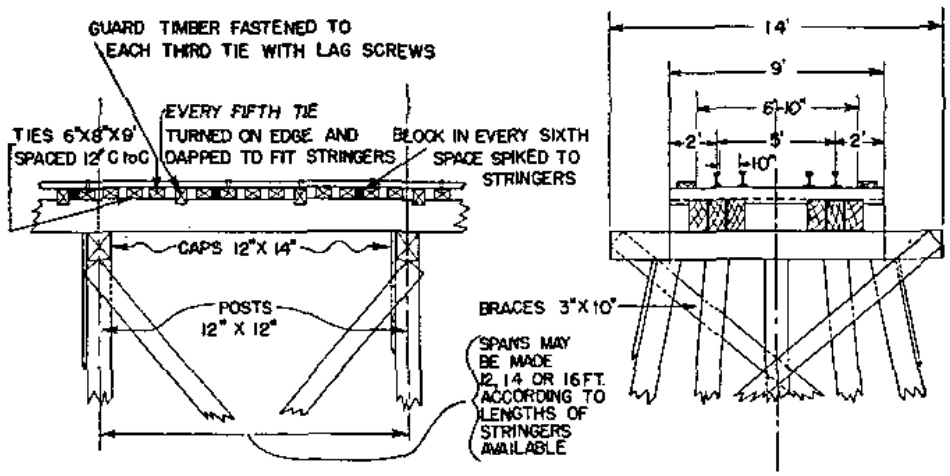


FIGURE 89.—Floor system for standard gage railway timber or pile trestle.

it can be avoided. The approaches at each end should be straight and nearly level for a distance of at least twice the maximum train length. This requirement will generally preclude the use of military ponton bridges for railways, even in emergencies, although the 23-ton bridge is capable of sustaining the imposed load of light military rolling stock, when reinforced by the employment of double the number of boats. Foundations must be especially unyielding as settlement is more troublesome than for lighter loads in other bridges. In double-track bridges the distance from center to center of tracks must not be less than 13 feet.

b. Creeping and sluing.—The ties of a railway bridge should be spaced from 4 to 6 inches apart, and about every sixth tie should be fastened to the stringers by nailing a block to the stringer to fill completely the space between that tie and the next. This prevents creeping of the track on the bridge. The track is prevented from sluing sideways by turning every fifth tie on edge and dapping it to fit the stringers.

c. Guard timbers.—These are placed parallel to and outside the track rails, on top of the ties, for which recesses 1 inch deep are provided. The guard timbers are usually 6 by 8 inches in cross section and are bolted to every second or third tie. Their purpose is to hold the ties at proper spacing and keep them from spreading in case of derailment. Guardrails are generally placed 8 to 10 inches away from and between the running rails in connection with the employment of guard timbers, their purpose being to keep the wheels from overrunning the guard timbers when a derailment occurs. The outer guard timbers should be at least 6 feet 10 inches apart when 10 inches of clear space is provided between the guard and running rails.

■ 159. REHABILITATION OF CAPTURED RAILWAYS.—*a. Reconnaissance.*—The reconnaissance is of special importance because the information thus obtained becomes a basis for determining the kind and quantity of material to be procured and the priority of work. The reconnaissance should preferably be made by the commander of the troops charged with the reconstruction. Especial attention should be paid to the discovery of stocks of track materials and sources of ballast which could be used.

b. Probable character of damage.—Deliberate demolitions of the line to a greater or less extent must be anticipated. Bridges will be found destroyed, tunnels blocked, track removed or damaged by explosives, ties removed and possibly burned, and stations and watering and fueling facilities demolished. Contact or delayed action mines may have been placed in the roadbed or bridge abutments and piers. In addition to deliberate demolitions by the enemy, it may be expected that the roadbed will be found damaged by shell fire, weakened by the construction of cave shelters in embankments, and deteriorated as a result of neglect and the forces of nature. (See FM 5-25.)

c. Priority of work.—The first consideration is to restore single-track operation. This includes the provision of passing tracks and locomotive watering facilities. In the case of a double-track line, advantage is taken of those portions of either existing track which can be most easily repaired, connecting the useful parts of both tracks by short sections of track in order to get a serviceable single track as soon as possible. All conditions of surface, line, and drainage except the worst that would interfere with train operation are corrected after a single-track line has been established.

d. Execution of work.—Time is saved by sending working parties forward by motor transport or marching in advance of the construction railhead to make repairs to the roadbed and clear it of damaged rail, ties, and other debris. This facilitates the work of the tracklaying party which is pushed forward with the work train. Materials may be salvaged from spurs and sidings to make repairs to the main line. Where bridges have been destroyed or tunnels effectively blocked, diversion or shoofly tracks may be contstructed to circumvent the obstruction temporarily, but before undertaking such steps the engineer should first carefully compare the labor and time of constructing the detour with that required to correct the difficulty on the existing line. Quarries and gravel pits are opened up at convenient points along the line for procurement of ballast. In order to expedite the work standards of alinement, surface of track and materials may be acceptable which are only strict enough to permit of low speed operation, but careful attention must be given to essential requirements, such as clearances, maximum curvature, maximum grade, and the prevention of soft spots in the roadbed.

SECTION IV

MAINTENANCE OF WAY

■ 160. SECTION WORK.—A section comprises from 5 to 7 miles of single track, and where practicable the middle of the section lies at a station. The section foreman sees that the rail joints are kept up, that the crossings are in repair, that the track is kept in alinement, that bad ties are replaced with good ones, and that a thorough inspection is made of his section as often as the conditions necessitate, and always once a day. He keeps a sharp lookout for broken rails, fires on wooden structures, and washouts. During rainstorms he patrols his section and immediately reports any danger that may threaten, and stops all traffic if necessary or places slow orders until proper repairs have been made. He inspects for and reports any break in the telegraph lines, sabotage, and unusual occurrences.

■ 161. TRACK MAINTENANCE.—Constant attention is necessary to keep track in good condition. The principal points to be attended to are—

a. To keep all ditches and drains clear, and to deepen them rather than to allow them to grow shallow.

b. To keep spikes and bolts tight, rails in line and grade, and the ties solidly tamped.

c. To remove worn-out or broken rails and ties.

For a military road the repair of damage caused by the enemy will furnish a large percentage of maintenance work, in forward areas.

■ 162. TAMPING.—Tamping in maintenance is a slightly different operation from tamping new track, and other tools are used. The space to be tamped is that between the tie and a trough in a well packed ballast. A tamping bar may be used for fine ballast, and a tamping pick (fig. 86) for broken stone. The tie is nipped up, as in new work, and the tamping is tight under the rails and only snug at the middle. Surfacing will be required in the spring if the track is on dirt or gravel ballast, and in any kind of ballast if the drainage is not good and the frost is deep. If there are especially bad spots on the section, they should be attended to first; otherwise, it is best to begin at one end and work continuously to the other. Send men ahead to set up bolts, nip up ties, and set spikes, and, if necessary, to gage the track, so that when the surfacing gang follows it has nothing to do but line and tamp. With tamping bars, two men should work on a tie opposite each other, striking simultaneously. Compressed air or gasoline tampers should be used if available. In cold climates, it may be necessary to use shims for surfacing during the winter, in which case they should be removed as rapidly as possible in the spring. These are blocks of wood of various thickness which are inserted between the rail and the tie to bring the rail to surface when the ballast is frozen too hard to be worked.

■ 163. RENEWING TIES.—To renew a tie—

a. Draw the spikes with a claw bar (fig. 86).

b. Dig out under the tie until it drops clear of the rail, strike a pick in one end, and draw the tie out.

c. Slip the new tie in its place, spike, and tamp.

■ 164. RENEWING RAILS.—To renew a rail—

a. Place the new one alongside the old one and see that it is of the right length.

b. Draw or loosen the inside spikes.

c. When all is ready, slip the old rail out of place and lift the new one in.

d. Set part of the inner spikes as quickly as possible, and the rest before the first train passes, if possible.

Be sure that the old rail is not disturbed until everything is ready. Figure 86 shows the usual form of spike maul. Its average weight is 8 pounds. The handle should be 3 feet long and in driving the hammer should be swung at the full length of the handle. Figure 86 also shows a track chisel. Its average weight is 4 pounds. It is used with a short handle, which must not be tight in the eye. In frosty weather a chisel should be warmed before using. A little oil will make a chisel cut faster and last longer. In addition to keeping the cutting edge properly sharpened, the struck end should be cleaned up and trued whenever it becomes badly broomed, ragged, or battered.

■ 165. RE-LAYING RAIL.—A party should work on one line of rail for perhaps half a day, and then move back to the other rail. A long line of old rail may be lined out at one time, but in placing the new rail the best results are obtained by laying it rail by rail. In an emergency it may be bolted together, and then lined in, but it is difficult to make the proper provision for expansion with this method. A test may show that it is necessary to pull only one line of spikes on each rail, even when the new rail is of different weight and section, and still obtain the proper gage. This saves time and material. After the old rail is thrown out, old spike holes should be plugged and ties adzed as necessary to give a solid bearing for the new rail. To allow a train to pass, a temporary connection may be made by use of a switch point. Bolt the switch point to the new rail and spike the toe of the switch point set to gage against the old rail. A connection of this kind should not be left in the track over night, or without a flagman who will make trains reduce speed over it. Old spikes, if undamaged, may be used again, but should be heated in a fire to remove oil or heavy rust.

■ 166. MAINTENANCE OF SWITCHES.—Daily inspections, adjustment and oiling of switches, and taking care of lamps are duties of a trackwalker.

a. Switches should be inspected for signs of spread track through the turn-out. The test for this is to observe whether the spike heads have been pushed out by the spreading of the rail, and by testing with a track gage. In case spread track is found, spikes must be pulled and reset in firm timber. Moving tie plates to allow resetting is generally necessary.

b. Switches should also be inspected for adjustment of points. Points must fit up to the stock rail with a tolerance of one-sixteenth of an inch. A throw of less than 3½ inches is dangerous on account of the possibility of a flange of a wheel striking the switch point.

c. Slide plates under the switch should be kept clean by sweeping, and they should be oiled.

d. Switch stands should be inspected to see that the creeping of the rail has not forced them against the switch ties, thus interfering with the throwing of the switch.

e. The main line and turn-out tracks should be tested for gage at the frog, since tight gage in either track at the frog may cause derailment.

f. Guard rails must be examined to see that they are fitting properly, that there are no broken parts, and that they provide flangeway not in excess of 1¾ inches at the middle of the guard rails opposite the frog point.

g. All rail joints through the turn-out should be inspected and bolts tightened when they are found loose.

■ 167. MAINTENANCE OF SIGNALS.—Signals such as switch targets, semaphores, and switch lamps are inspected and maintained by a trackwalker. Maintenance consists of cleaning and testing lamps, seeing that they are properly focused, polishing the glass lenses, and observing the operating switches to see that they are in working order. Lamps should be tested and cleaned periodically, at short intervals.

■ 168. MAINTENANCE OF BRIDGES.—Bridges should be carefully inspected periodically by qualified bridge inspectors, as explained in chapter 2.

■ 169. MAINTENANCE OF WATER SUPPLY.—When a wooden water tank is found to be leaking badly there are a number of ways of effecting repairs of a more or less permanent nature.

a. If the tank has not been used for some time and is leaking through the seams, excelsior or sawdust will be found effective if dumped in when the tank is full. This material will float on top of the water. The tank is then allowed to drain and as the water level recedes, the sawdust or excelsior is drawn into the seams where it lodges. The tank is then refilled and the staves are allowed to swell, the excelsior or sawdust acting as caulking.

b. Where bullet or worm holes occur, these holes can be stopped by driving soft wooden plugs into them from the outside.

c. Where an area is riddled by worm holes or rot or from other causes, repairs can best be made from the inside by tacking to the affected area a sheet of rubber made from an automobile inner tube.

d. Where the wooden floor of the tank is leaking badly due to old or decayed floor sills, the bottom of the tank being allowed to settle and the seams to open, the best quick repair is to raise the foot valve inside the tank about 6 or 8 inches above the bottom, to place reinforcement of small iron rods or pipe, and to pour 6 or 8 inches of concrete into the bottom of the tank.

SECTION V

ROLLING STOCK

■ 170. ROLLING STOCK.—*a. Definition and requirements.*—The rolling stock of a railroad consists of all the locomotives and cars used for moving personnel and supplies over the lines. To meet special military needs and facilitate procurement in war, plans have been made for 20-ton cars of four general types, all mounted on identical underframes; they may be drawn by steam or gasoline-mechanical locomotives. This rolling stock is designed to meet the requirements of military railway transportation which are as follows:

(1) Movements of troops to the front.
(2) Strategic troop movements.
(3) Evacuation of sick and wounded.
(4) Movements of supplies to troops.

b. Special military rolling stock.—The four types of cars mentioned in the preceding paragraph and shown in figures 90 to 93, inclusive, are—

(1) Box, used for supplies, hospital cars, troops and animals.

(2) Flat-gondola, used for transporting supplies not requiring protection from the weather.

(3) Tank, for transporting gasoline and other liquids.

(4) Caboose, for convenience (shelter and use) of the train crew.

Hospital trains are made up, front to rear, of 1 kitchen car, 1 ward car, approximately 19 dressing cars, and 1 personnel car. All these may be adaptations of the military box car. The steam locomotive considered most desirable is a consolidation type with a designed weight of 75 tons on its four driving axles. It has 50-inch driving wheels, and cylinders of 21-inch diameter and 26-inch stroke. Its normal tractive force is 37,000 pounds. The tender has a capacity of 7,000 gallons of water and 10 tons of coal, with a loaded weight of 64 tons. At its maximum rate, this locomotive will consume about 4,400 pounds of coal and 3,400 gallons of water per hour. Under average conditions it will haul a 1,000-ton train with a 500-ton pay load. Such a train will require a siding about 1,400 feet long. In forward areas the preferred type of locomotive is one with a gasoline engine and a mechanical transmission. This light locomotive will have a weight of 30 tons and a hauling capacity considerably less than the steam locomotive, but still sufficient to haul half-size trains at per-

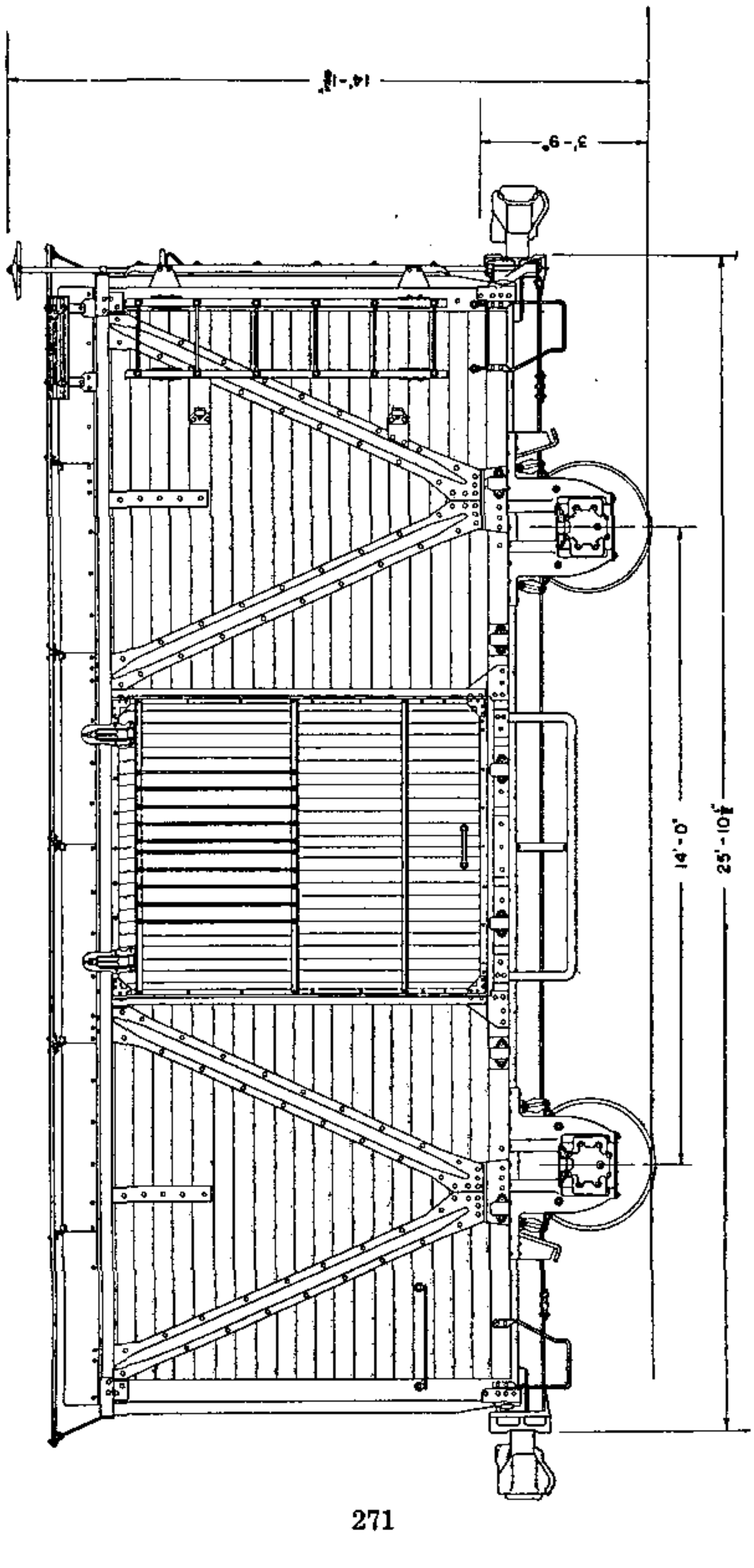


FIGURE 90.—Box car, 20-ton.

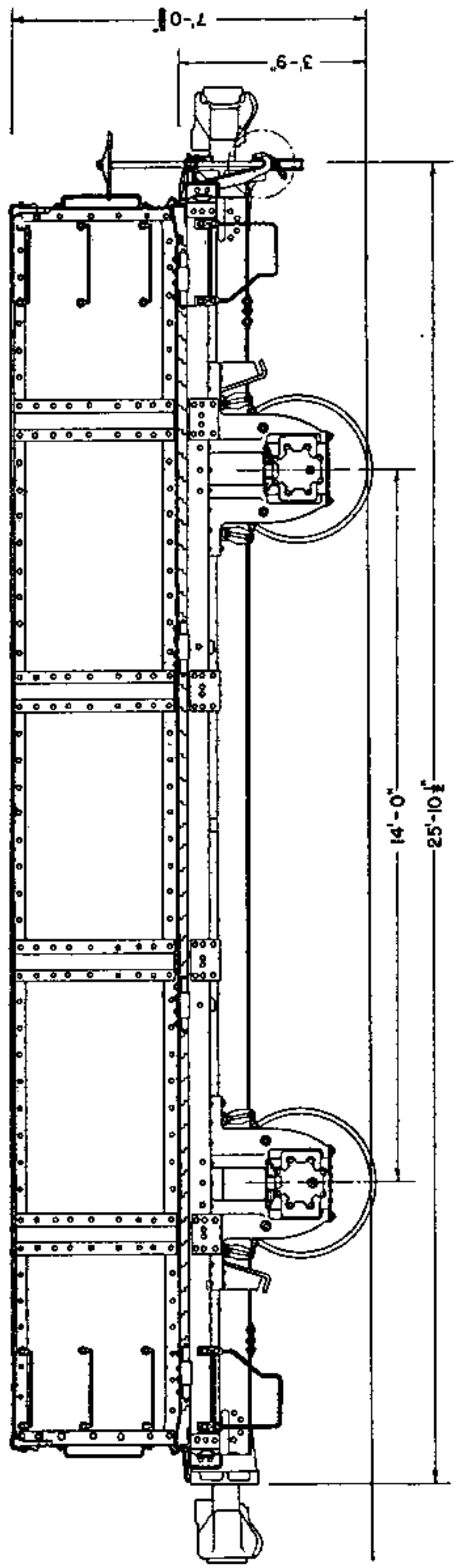


FIGURE 91.—Combined flat and gondola car, 20-ton.

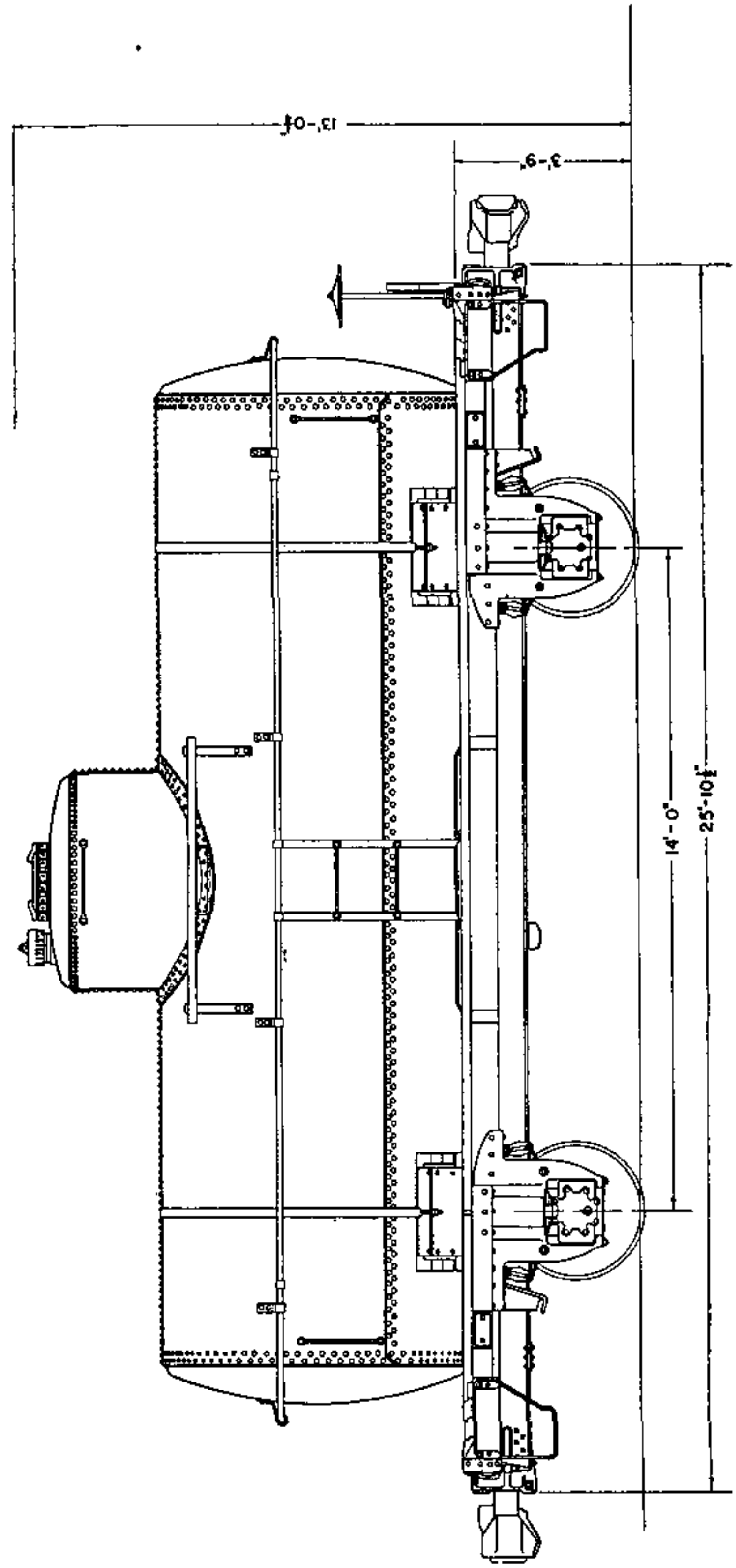


FIGURE 92.—Tank car, 5,000-gallon, 20-ton.

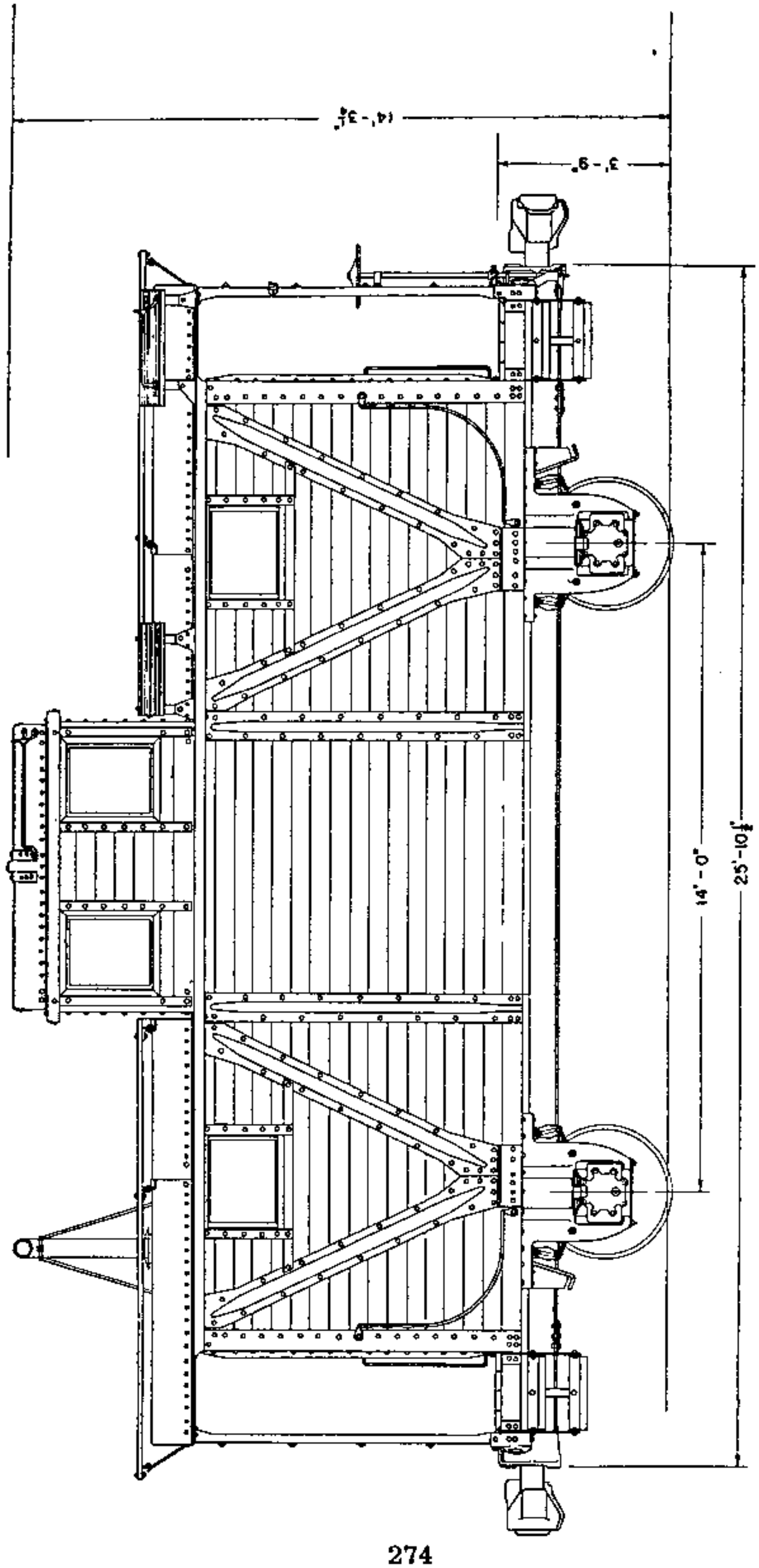


FIGURE 93.—Caboose, 4-wheel, 20-ton.

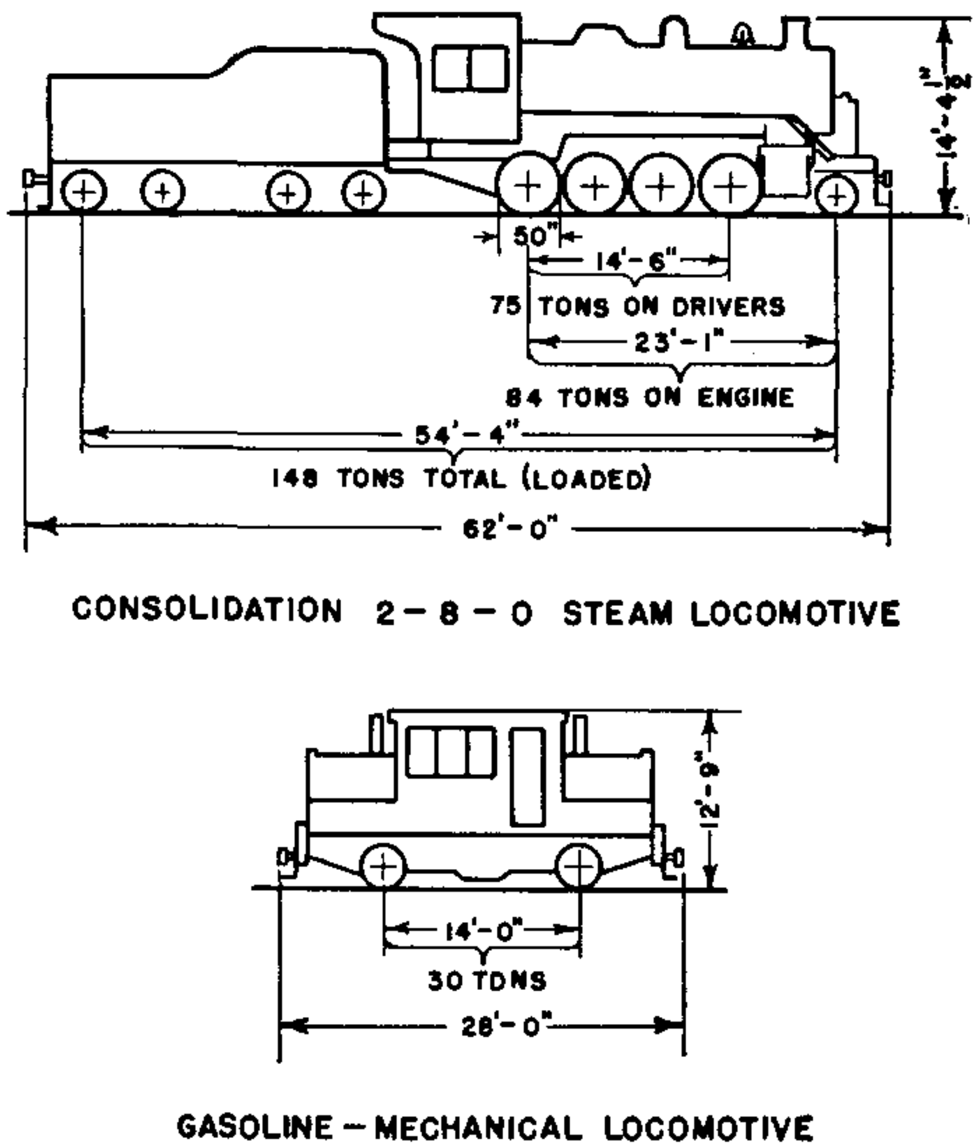


FIGURE 94.—Standard locomotives.

missible speeds. Its consumption of gasoline will run to only about 50 gallons per hour, and no water or maintenance facilities are required in excess of those essential for heavy trucks.

Figure 94 illustrates the comparative sizes and appearance of the steam and light locomotives.

c. *Commercial rolling stock.*—Locomotives are classed according to the number of forward truck wheels, drivers, and rear truck wheels, considered in that order. Thus an engine with 2 forward truck wheels, 4 drivers, and 2 rear truck wheels is indicated by the designation, 2–4–2. Other types are similarly designated. The cars include coaches, sleepers, box cars, tank cars, stock cars, flat cars, gondolas, cabooses, and special cars such as refrigerators, wrecking cars, hospital cars, and kitchen cars. For data as to dimensions and capacities see tables XLII and XLIII.

TABLE XLII.—*Dimensions and capacities, typical standard-gage rolling stock*

Class	Dimensions				Capacity				
	Length inside measurement (feet)	Width (feet)	Height (feet)	Approximate weight (empty in tons)	Tons	Cubic feet, approximate	Floor space, (square feet)	Animals	Men (allowing about 8 square feet per man and equipment)
Box	34	8	7	15	30	1,900	272	19	34
	36	8	8	20	40	2,300	288	20	36
	40.5	8.5	8	23	50	2,750	344	22	43
Flat	38	9	------	17	40	--------	342	------	------
	40	9.2	------	20	50	--------	370	------	------
	42	9.5	------	25	70	--------	399	------	------
Stock	36	8.5	7.6	14	30	2,300	306	20	------
	36	8.5	8	18	40	2,450	306	20	------
Gondola	34	8.5	2.6	20	40	720	289	------	------
	40.5	8.8	2.6	25	50	890	354	------	------
	46	9.5	3	30	70	1,310	437	------	------
Automobile	36	8.5	8	20	40	2,450	306	20	38
	40.5	8.8	9	24	50	3,250	364	22	45
Tank	35	6.5	------	20	40	8,000 gals.	------	------	------
	33.5	7.2	------	25	50	10,000 gals.	------	------	------
Refrigerator	30	8	7	16	30	1,680	240	(1)	(1)
	33	8.3	7.6	21	40	2,060	275	(2)	(2)
Baggage	60	9	------	50	------	--------	540	------	------
Caboose	31.5	8.5	6.8	20	------	--------	------	------	------
Diner	80.5	------	------	80	------	--------	------	------	------
					Passenger capacity				
					2 per double seat	3 per 2 double seats	3 per section		
Coach	63	------	------	60	70	46	------	------	------
Sleeper, 12 sections and drawing room	74	------	------	70	------	--------	40	------	------
Sleeper, 16 sections	74	------	------	70	------	--------	48	------	------

[1] Ice capacity, 4 tons.
[2] Ice capacity, 5 tons.

TABLE XLIII.—*Standard gage railway—maximum bulk loading for freight cars*

Rated capacity of cars in tons	20	30	40	50
Length of cars in feet (approximate inside dimension)	24	36	42	50
Items	Actual capacity of cars, in tons			
Ammunition	20	30	40	50
Barbed wire	20	30	40	50
Blankets, baled	18	27	32	40
Bread	12	19	24	30
Brick	20	30	40	50
Burlap, rolls	14	22	28	35
Cable, steel	20	30	40	50
Canned goods, boxes	20	30	36	45
Cement	20	30	40	50
Chicken wire	12	18	20	25
Clothing, baled	18	27	32	40
Coal	20	30	40	50
Coke	12	18	24	30
Flour	20	30	40	50
Frogs and switches	20	30	40	50
Gravel	20	30	40	50
Harness and saddling	12	18	20	30
Hay, baled	10	15	14	20
Iron, corrugated	20	30	40	50
Meat	10	15	24	35
Motor vehicle parts	16	24	28	40
Nails	20	30	40	50
Oats	12	18	24	30
Pipe, iron	20	30	40	50
Rail	20	30	40	50
Rifles, in chests	20	30	40	50
Rope, manila	12	18	24	30
Sand	20	30	40	50
Sandbags	14	21	24	30
Stone, any form	20	30	40	50
Sugar	20	30	40	50
Tar paper	10	15	20	30
Telephone wire	20	30	40	50
Tentage	10	15	20	30
Ties, track	12	19	26	32
Timber, logs	12	18	24	30
Timber, sawed	14	21	28	35
Tires, pneumatic	12	18	24	40

TABLE XIII—*Standard gage railway—maximum bulk loading for freight cars*—Continued

Rated capacity of cars in tons	20	30	40	50
Length of cars in feet (approximate inside dimension)	24	36	42	50
Items	Actual capacity of cars, in tons			
Tools, engineer	20	30	40	50
Tools, shop	20	30	40	50
Tools, truck	20	30	40	50
Track, fastenings	20	30	40	50

NOTE.—A rated capacity in tons of a car does not mean that this rated tonnage of all articles can be carried. This table shows the tonnage of military freight which can be carried in freight cars of common rated capacities. The 20-ton car is indicated by column one.

■ 171. STANDARD TRAINS.—The logistical planning of troop movements by train is facilitated when use can be made of so-called standard trains. These are made up in one or more (usually two) general types from box cars, flat cars, coaches, and cabooses. Hospital trains will initially consist entirely of standard commercial cars or military box cars, converted for this use as indicated in the preceding paragraph. Standard trains may be made up from commercial rolling stock or from that of special military design, and, in either case, box cars may be used for men, supplies, and equipment, or for animals. Stock cars are, of course, desirable for the latter. If commercial freight cars are employed, special precautions may be necessary to make them suitable for troops or animals. For troops, the problem of ventilation is simple; openings of sufficient size can be made near the roofs of the cars without damaging them, or doors may be kept partly open. For animals, lattice doors may be provided or large openings may be made in the doors and covered with wire. Flat cars are used almost exclusively for the movement of wheeled vehicles, tractors, guns, and similar equipment. When possible they should be placed end to end within a train, preferably just ahead of the caboose. This facilitates loading and unloading by the use of an end ramp and crossovers as explained in paragraph 172. In order to be available for moving troops quickly, which is the only reason for the existence of standard trains, they must be able to reach the point where the troops are to entrain within a few hours at most. To enable them to do this they must be held near the point in the theater of operations where they probably will be needed, and must be used for no purpose that will interfere materially with the purpose for which they are intended. This means that their use will be limited generally to the movement of troops within or between adjacent theaters of operations. The capacity of the standard 20-ton box car is 30 men or 8 horses. The capacity of the standard commercial box car is 60 men, 8 horses plus 16 men, or 15 horses.

SECTION VI

METHODS OF CAR LOADING

■ 172. LOADING OF ANIMALS AND VEHICLES.—Loading of wheel or tractor vehicles, or animals, is best accomplished by the use of ramps. For animals, the ramps may be constructed of timber with a cleated floor, or built up by lashing bales of hay together in the form of steps. To load vehicles on a train of flat cars, end ramps are generally employed, together with crossovers to span the gaps between cars. A simple type of end ramp can be constructed by building up a crib near the end of the last car, using railroad ties or similar timber. Four end-beveled planks, 2 inches by 12 inches by 12 feet, held together by cross members are then placed in such manner that they are supported by the end of the car, the crib, and the ground, and are then secured by nailing and staking. The disadvantage of this ramp and all others of similar nature is in the steepness of its slope, which requires that vehicles be hauled up by block and tackle. Better results can be obtained by using railroad jacks to remove the rear truck from the last car, letting the end of the car down to the ground and bridging with a short, low ramp. In this way the whole rear car becomes a ramp and when all cars including itself are loaded, the lowered end can be jacked up on its truck.

■ 173. LOADING OF SUPPLIES.—In the case of supplies contained in heavy bales and boxes, loading may be direct to cars from platforms or by ramps similar to those described in the preceding paragraph. Full use should be made, where possible, of standard commercial equipment such as hand trucks, electric hoists, etc. Loading is facilitated by the availability of adequate storage and handling space and by the proper arrangement of warehouses with platforms adjacent to the tracks.

■ 174. SECURING LOADS ON CARS.—In loading supplies, vehicles, etc., on open top cars, consideration should be given to the proper placing and securing of the load. The load must not exceed the capacity of the car; it must be placed so that it will not interfere with train operation nor create an unnecessary hazard for railroad personnel; it must be securely fastened so that no shifting will occur in transit; and the loaded car must be able to clear all obstructions, such as tunnels and bridges, along the line. The construction of the car and the number and location of bearing pieces upon which the load rests have an influence on the weight of load that can be carried. The load must not be placed so that more weight falls on one side of the car than the other. In the case of a load overhanging the end of a car, an empty flat car should be used as an idler, or the load may be supported on both cars. If the load is very long, three cars may be used, with the load supported on the end cars and the center car as an idler. For safety in these cases, the couplers must be blocked to fully compress the draft gear, and the uncoupling mechanism made inoperative on all cars involved. Loads may be secured to the car by hardwood stakes, braces, or cleats, and by bolts, rods, wire, or steel bands. A load on one car only must be placed to allow room for access to and operation of the hand brake. For loads requiring more than one car, at least one hand brake out of three must be accessible and operative. All vehicles must be held securely in place by blocking cleats and/or lashings. In the case of large gun carriages or heavy trucks on pneumatic tires the lashings can be drawn tight by deflating the tires, taking up on the lashings, and again inflating the tires.

SECTION VII

SUMMARY

■ 175. SUMMARY.—*a*. Railways are superior to any other form of land transportation for bulk movements of supplies and troops over distances greater than about 75 miles.

b. Advantage is to be taken of existing lines, and no attempt will be made to procure permanence in new construction.

c. Roadbed and track will be as light as is consistent with the objects to be attained.

d. The efficient moving of freight requires full use of car capacities, prompt handling, and adequate storage facilities.

e. Inadequate terminal facilities limit the capacity of a railway as a whole.

f. Full use will be made of available commercial rolling stock.

g. Car loading is largely a matter of expediency, aided by the application of ingenuity and common sense.

h. General engineer troops must be prepared to construct, reconstruct, maintain, and repair short lengths of line.

i. In maintaining a railway line, first attention should be given to bridges, tunnels, terminals, and similar vulnerable points.

j. Continual reconnaissance is vital to the maintenance of a railway.

CHAPTER 6

CONSTRUCTION IN WAR

SECTION I

GENERAL

■ 176. GENERAL.—*a. Simplicity.*—All construction in the theater of operations is of the simplest nature. Only common construction materials and supplies should be used.

b. Economy of materials.—Economy of materials is obtained by—

(1) Limiting all construction to temporary, emergency facilities, providing only the barest necessities.

(2) Maximum use of existing structures and local materials.

(3) Use of type plans.

c. Type plans.—Type plans, such as those illustrated in this manual permit efficient utilization of personnel, materials, and available time. Detailed type plans are prepared in peacetime by the Corps of Engineers. They are the basis for the procurement of standardized materials to be shipped to the theater of operations.

d. Provision for expansion.—Projects should be laid out so that future expansion is feasible if any possible need for expansion can be foreseen. So far as practicable the project should be planned in its entirety and a suitable site chosen. Only units actually needed are constructed initially. They are practically completed before beginning additional work, even though an uneconomical working schedule results. The object is to obtain complete units for early use and to avoid work on units which later changes in plan may cause to be abandoned.

TABLE XLIV.—*Development and execution of a project*

Action	Taken by—
1. Obtain authority	Arm or service desiring.
2. Prepare project	Representatives of arm or service desiring construction, and of section engineer.
3. Submit report outlining project	Representative of section engineer.
4. Preliminary reconnaissance	Engineer of section of communications zone in which project is located.
5. Selection of site	Same.
6. Procure or make detailed topographic survey and prepare map of site.	Same.
7. Adapt type plans	Same.
8. Procure supplies	Same.
9. Lay out buildings, grounds, and outside utilities.	Same.
10. Initiate construction with nucleus of construction force. (General service troops suitable.)	Same.
11. Build up force as necessary and complete construction.	Same.

■ 177. SCOPE AND SITES.—*a. Scope of engineer construction.*—Among the facilities to be constructed by the engineers in the theater of operations are the following which are generally covered in this volume:

(1) *For use by two or more arms or services.*

(*a*) Semipermanent camps at ports, training centers, and rest areas.

(*b*) Ports.

(*c*) General depots.

(*d*) Administrative facilities.

(2) *For the Medical Department.*

(*a*) Station hospitals.

(*b*) General hospitals.

(*c*) Veterinary hospitals.

(3) *For the Quartermaster Corps.*

(*a*) Quartermaster supply depots, including gasoline and oil-storage facilities.

(b) Commissaries, including warehouses, bakeries, coffee-roasting plants, and cold-storage plants.

(c) Remount depots.

(d) Motor transport depots.

(e) Delousing plants.

(f) Laundries and dry-cleaning plants.

(4) *For the Ordnance Department.*

(a) Ammunition depots.

(b) Repair and maintenance depots.

(c) Ordnance supply depots.

(5) *For the Air Corps.*

(a) Airdromes.

(b) Repair depots.

(c) Assembly plants.

(d) Air Corps supply depots.

(e) Training centers.

(6) *For the Corps of Engineers.*

(a) Engineer supply depots.

(b) Railway facilities.

(c) Utilities.

(7) *For other arms or services.*

(a) Arm or service supply depots.

(b) Miscellaneous small installations.

b. *Reconnaissance.*—Features to be considered in reconnoitering for construction sites are tabulated below.

TABLE XLV.—*Construction sites*

FEATURES APPLYING TO ALL TYPES OF CONSTRUCTION SITES

(1) Sufficient size for present needs and future possible expansion.
(2) Adequate water supply.
(3) On or near railroad of sufficient capacity for supply and personnel movement.
(4) Available for lease (if not already owned or leased by the Government for period up to 5 years.
(5) Largely free from floods.
(6) Adequate drainage.
(7) Roads good or potentially good.
(8) Climate favorable.
(9) No insect pests.
(10) Location strategically convenient.
(11) Material and labor locally available at reasonable prices.

ADDITIONAL FEATURES APPLYING TO CAMP SITES PRIMARILY

(12) Accessib'e to adequate training area.
(13) Accessible to suitable target-range area.
(14) Recreational facilities nearby.
(15) Grazing facilities for animals. (Applies also to remount-depot sites.)

■ 178. ORGANIZATION.—Construction of a large project requires an adequate overhead organization. Assignment of working personnel to the job is governed usually by the receipt of materials. The working force should be initially small and then should be increased as construction progress demands. Construction in the theater of operations may be either with troop or civilian labor. The latter may be either hired labor under military supervision or labor employed by a private contractor. The organization chart in figure 95 is generally suitable for large construction projects prosecuted with troop labor.

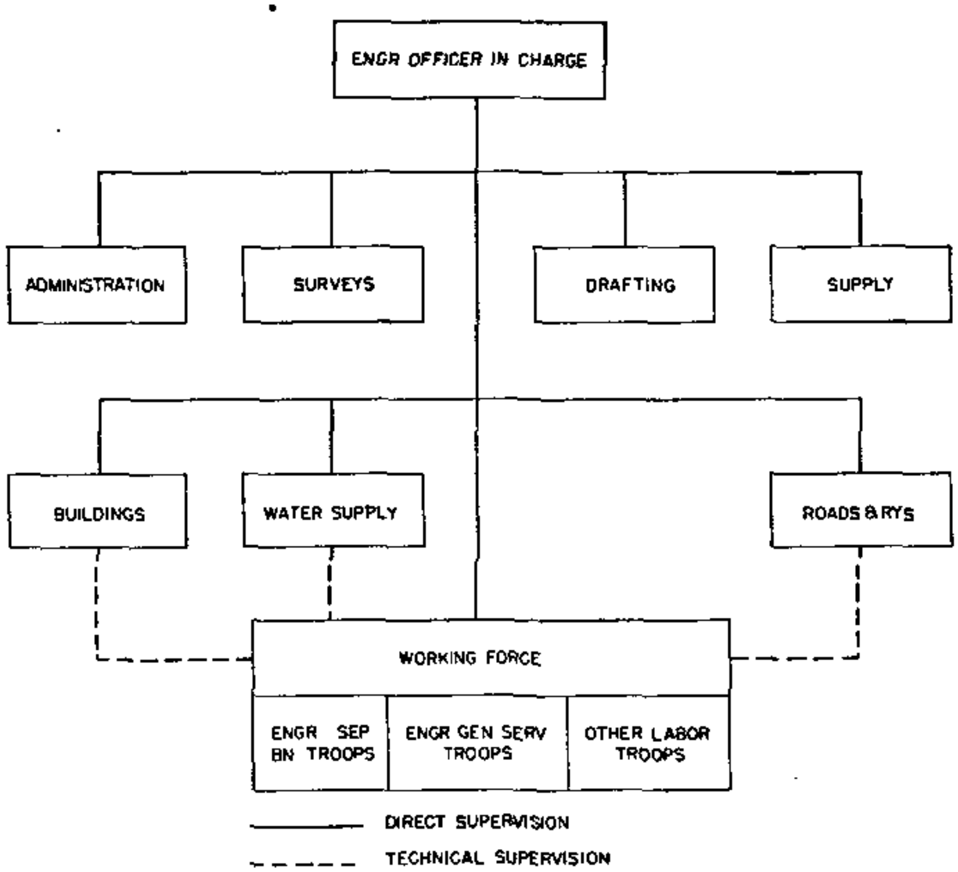


FIGURE 95.—A typical organization chart for a large project.

■ 179. SUPPLY.—*a. Local material.*—Local material sufficient for construction of a large project rarely will be available. Local sources should, however, be exploited to capacity, by such means as milling of local timber and development of quarries.

b. Shipments.—The majority of supplies must be procured and transported to the construction site. Great difficulty is frequently caused by temporary lack of nails, bolts, and similar items. In shipment, rails should be accompanied by bolts and spikes, roofing by nails and tacks. Structures should be shipped complete, because field classification and assembly are difficult.

■ 180. AIR DEFENSE MEASURES.—Defense of military facilities from aerial attack is easier if certain provisions are made in construction. The usual means of defense are here briefly discussed.

a. Dispersion.—Intervals between buildings or supply piles, which are standard precautions against fire, limit the amount of damage from aerial bombing.

b. Concealment and camouflage.—Installations often may be partially hidden or disguised, camouflage measures and natural concealment being used. Dummy installations aid in deception. (See FM 5–20.)

TABLE XLVI.—*Defensive measures for installations in the theater of operations*

Facility	Defensive measures most practicable
Camps and hospitals	Dispersion.
General and arm or service depots	Antiaircraft weapons. Own aviation. Dispersion.
Ammunition depots	Antiaircraft weapons. Own aviation. Dispersion. Camouflage and concealment.
Airdromes	Antiaircraft weapons. Own aviation. Dispersion. Camouflage and concealment.

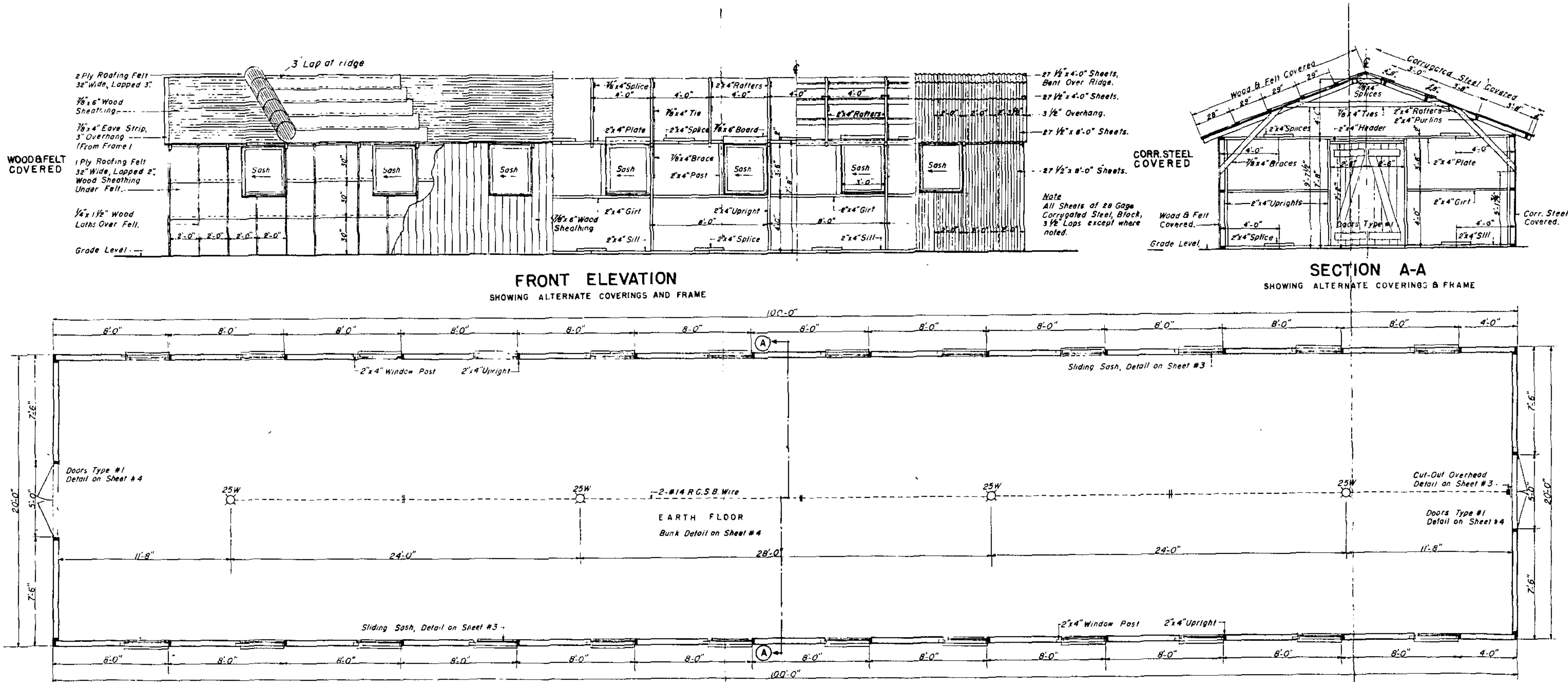
c. *Active defenses.*—Active defense is provided by antiaircraft weapons and by friendly aviation.

SECTION II

TROOP FACILITIES

■ 181. STANDARD BUILDING.—*a. Discussion.*—Figure 96 shows the standard 20- by 100-foot building. This building is designed for a variety of uses, such as barracks, warehouses, mess halls, administration buildings, infirmaries, hospital wards, etc. It is essentially a lightweight frame, sheathed with wood or corrugated steel. Standard sizes of lumber are used. Bracing is limited to essentials; the stability of the structure depends partly upon the stiffness of the complete assembly of sides and ends. Corrugated steel is the simplest covering, but should not be used in hospitals because it is hot in summer and cold in winter. Common batten doors (fig. 97) are used, with any simple available hardware. They may be single or double, covered with either corrugated steel or wood. Screen doors as shown in figure 98 are used only on hospital wards, kitchens, and mess halls. The window frame (fig. 99), assembled in the field, is either screened or covered with a translucent material. Glass is not used. Ventilators (fig. 100), when required, may be either the ridge type or the tubular metal type. Floors are used only when absolutely necessary. Figure 101 shows two types of floors. The type *A* floor is installed on level and the type *B* floor on uneven ground. Use of the latter should be avoided, as it is more costly.

b. Bill of materials.—A bill of materials for the standard building is given in table XLVII, below:



(Face p. 288)

FIGURE 96.—Standard building, 20 by 100 feet.

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TABLE XLVII.—*Bill of materials, standard building*

Bill number 1, for frame

Item	Quantity	Unit	Size	Length	Feet, board measure	Weight in pounds	Description
1	140	Piece	2 by 4 inches	8 feet	747	3,111	Lumber.
2	61	Piece	2 by 4 inches	12 feet	488	2,034	Lumber.
3	51	Piece	⅞ by 4 inches	12 feet	204	850	Lumber.
4	64	Piece	⅞ by 2 inches	12 feet	128	534	Lumber.
5	6	Piece	⅞ by 6 inches	12 feet	36	150	Lumber.
6	32	Pound	20d	4 inches		32	Nails.
7	11	Pound	10d	3 inches		11	Nails.
8	7	Pound	6d	2 inches		7	Nails.

Bill number 2, for wood and felt covered building (add to bill number 1)

Item	Quantity	Unit	Size	Length	Feet, board measure	Weight in pounds	Description
1	4	Piece	⅞ by 4 inches	12 feet	16	67	Lumber.
2	1,016	Piece	⅞ by 6 inches	8 feet	4,064	16,933	Lumber.
3	26	Roll	32 inches	40 feet 6 inches		1,040	2-ply "prepared roofing," including nails, metal caps and cement.
4	5	Roll	32 inches	162 feet		325	1-ply "prepared roofing," including nails, metal caps and cement.
5	300	Piece	¼ by 1½ inches	4 feet		150	Laths.
6	65	Pound	8d	2½ inches		65	Nails.
7	3	Pound	3d	1⅛ inches		3	Nails.

TABLE XLVII.—*Bill of materials, standard building*—Continued

Bill number 3, for corrugated steel covered building (add to bill number 1)

Item	Quantity	Unit	Size	Length	Feet, board measure	Weight in pounds	Description
1	100	Piece	2 by 4 inches	8 feet	534	2,225	Lumber.
2	26	Pound	20d	4 inches		26	Nails.
3	289	Piece	27½ inches	8 feet		3,613	2½-inch corrugated steel sheets, black, 28 gage.
4	22	Pound	7/16 inch	1½ inches		22	Nails, barbed, roofing, 10 gage.
5	11	Pound	3/16 inch	⅜ inch		11	Rivets.
6	11	Roll	36 inches	166 feet 8 inches		330	Building, paper.
7	18	Pound	No. 16			18	Wire, galvanized.
8	2	Pound	No. 14	¾ inch		2	Staples, poultry netting.
9	400	Piece	¼ by 1½ inches	4 feet		200	Laths.
10	2	Pound	3d	1⅛ inches		2	Nails, 15 gage.

NOTE.—*Materials* included in items Nos. 6, 7, 8, 9, and 10 will be used if insulation is required.

Bill number 4, for 24 sash

Item	Quantity	Unit	Size	Length	Feet, board measure	Weight in pounds	Description
1	48	Pieces	⅞ by 3 inches	12 feet	144	600	Lumber.
2	1	Roll	*38 inches*	*100 feet*		*50*	Transparent *plastic* sheet.
3	3	Pounds	4d	1½ inches		3¾	Nails.

Bill number 5, for 2 pairs of doors, type 1

1	4	Pieces	⅞ by 8 inches	8 feet	22	92	Lumber.
2	23	Pieces	⅞ by 6 inches	8 feet	92	383	Lumber.
3	2	Pieces	⅞ by 3 inches	8 feet	4	17	Lumber.
4	1	Piece	¾ inch	3 feet		½	Wood dowel.
5	8	Each		10 inches		20	T-hinges and necessary screws.
6	1½	Pounds	6d	2 inches		1½	Nails.
7	½	Pound	4d	1½ inches		½	Nails.
8	1	Piece	⅜ inch	12 feet		1	Rope, manila.
9	2	Each	½ inch	¾ inch		1	Screw eyes, wire, #106 Sargent or equal.
10	4	Each		3 inches		1	Screw hooks and eyes.

Bill number 6, for 50 two-man bunks

1	100	Pieces	2 by 4 inches	12 feet	800	3, 334	Lumber.
2	300	Pieces	⅞ by 6 inches	14 feet	2, 100	8, 750	Lumber.
3	136	Pieces	⅞ by 6 inches	8 feet	542	2, 266	Lumber.
4	26	Pieces	2 by 2 inches	8 feet	70	292	Lumber.
5	100	Pieces	⅞ by 3 inches	14 feet	350	1, 458	Lumber.
6	84	Pieces	⅞ by 3 inches	8 feet	168	700	Lumber.
7	28	Pounds	8d	2½ inches		28	Nails.
8	20	Pounds	6d	2 inches		20	Nails.
9	4	Pounds	3d	1¼ inches		4	Nails.

TABLE XLVII.—*Bill of materials, standard building.*—Continued

Bill number 7, electrical

Item	Quantity	Unit	Size	Length	Feet, board measure	Weight in pounds	Description
1	210	Feet	Number 14			5¼	Wire, R. C. S. B., solid copper.
2	1	Each	30 amperes, 125 volts.			1	Cutout, main line, plug fuse, double pole.
3	2	Each	15 amperes				Fuses, plug.
4	4	Each				1¼	Socket, pull, brass, *S22* (P. and S. cat. *38*, base B. P.).
5	50	Each	Number 12			7½	Knobs, split porcelain, with nail and leather washer.
6	2	Each	⅝ by 3 inches				Tubes, procelain.
7	4	*Each*	*25 watts*				*Lamps, Mazda, 115-volt.*
8	10	Each	1¼ inches				Screws, for cutout and socket, No. 8, F. H. bright.
9	4	Each		3 feet			Cord, linen, with chain and link tassel.

Number *of pieces of wood sheathing must be adjusted when specified width is not* available.

Allowance included for cutting waste only. To cover other losses add: For lumber, 3 percent (minimum, 1 piece each size), for nails, rivets, and screws, 10 percent.

TRANSPORT REQUIREMENTS

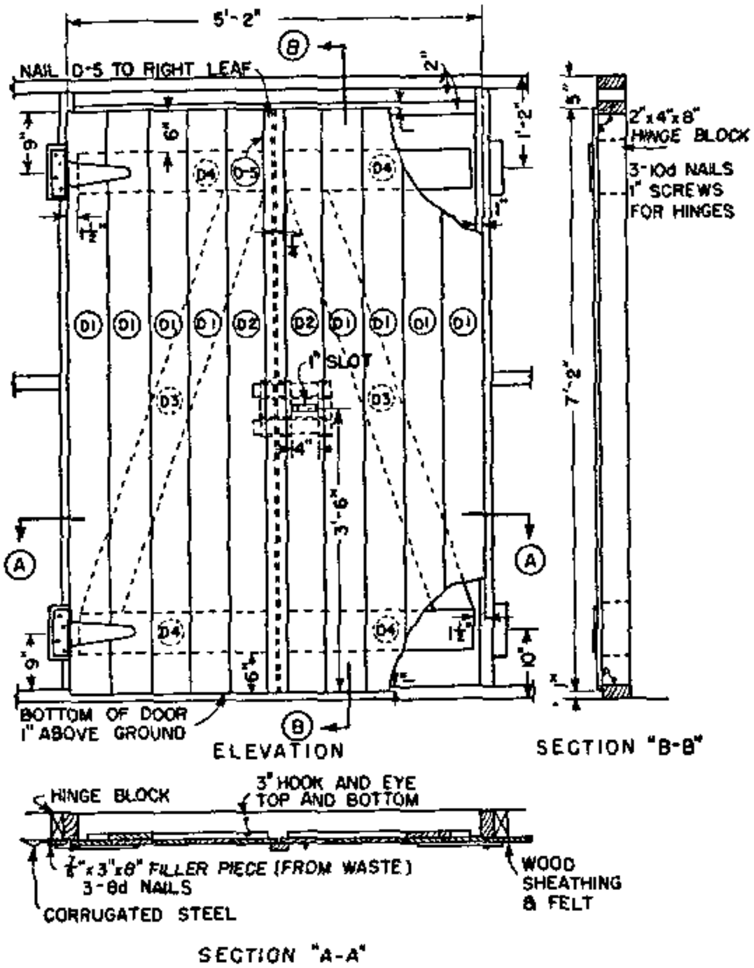
For wood and felt covered building

Material	Pe	Weight in pounds	Cubic feet	Truck loads
Lumber	Building	27,052	540.8	5
All other material	Building	1,841.5	55.2	1
Total	Building	28,893.5	596.0	6
Total	100 square feet	1,444.7	29.83	0.3

For corrugated steel covered building

Material	Pe	Weight in pounds	Cubic feet	Truck loads
Lumber	Building	10,738	215.2	2
All other material	Building	3,947	51.2	1
Total	Building	14,685	266.4	3
Total	100 square feet	734.25	13.32	0.15

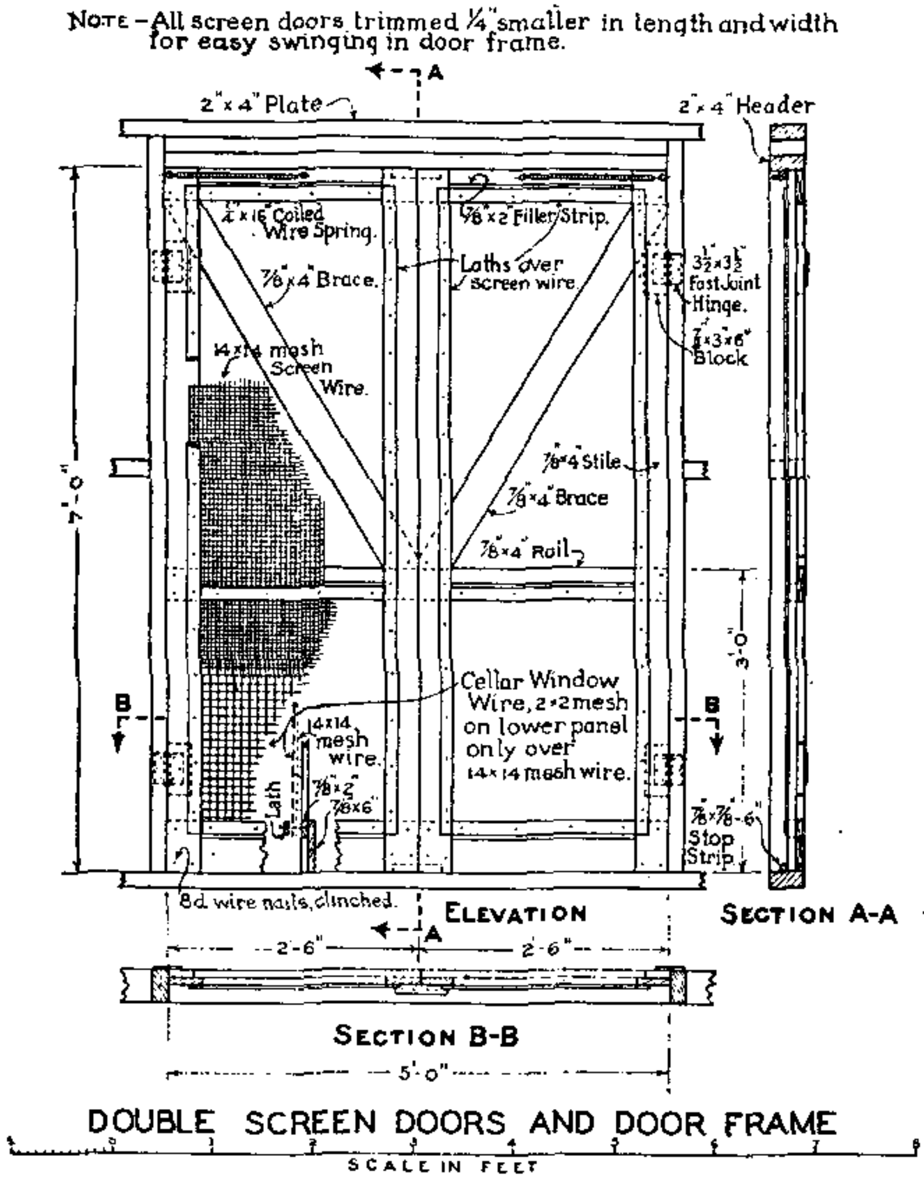
Truck capacity based on 1½-ton dump body type, with 100 percent overload.



DETAIL OF DOOR & FRAME

PIECES FOR PAIR OF DOORS TYPE 1 (TWO PAIR REQUIRED)					
DESCRIPTION	MARKED	NO. PC.	SIZE	L'GTH	APPLICATION
LUMBER	D1	8	7/8"x6"	7'-2"	
"	D2	2	7/8"x6 7/8"	7'-2"	
"	D3	2	7/8"x6"	5'-8"	
"	D4	4	7/8"x6"	2'-4"	
"	D5	1	7/8"x3"	7'-2"	
"	L1	5	7/8"x2"	8"	
"	L2	2	7/8"x2"	3"	
"	L3	1	7/8"x3"	10"	
"	L4	1	3/4" ø	10"	
NAILS		40	6d	2"	D4 to D1 & D2
"		30	6d	2"	D3 to D1 & D2
"		15	5d	1 3/4"	D5 to D2
"		8	6d	2"	L1 to D2
"		4	6d	2"	L2 to D2
"		12	6d	2"	L1 to L1 & L2
"		1	6d	2"	L3 to L4
HINGES		4	7	10"	
SCREWS		16		1"	

FIGURE 97.—Batten door, type 1.



BILL OF MATERIAL				
No. Pcs.	Size	Length	Ft. B.M.	Items.
4	7/8"x4"	14'-0"		Stiles, Top and Middle Rails, Diagonal Braces and Hinge Blocks.
2	7/8"x7/8"	14-0		Stop Strips " Filler Strips for Screen Wire.
1	7/8"x6"	6'-0"		Bottom Rails.
4	3½x3½			Fast Joint Hinges.
2	3"			Screw Hooks and Eyes.
2	¼"ø	16"		Coiled Wire Spring.
1	26" w.	14-0"		Screen Wire, 14x14 Mesh
1	26" w.	6-0"		Cellar Window Wire, 2x2 Mesh.
¼ lb.	5 d.			Nails for Strips and Blocks
½ "	8 d.			Nails " Framing.
¼ "	5/16"			Staples for Cellar Window Wire - Double Pointed.
1/8 "	No 3.			Tacks for Screen Wire.
¼ "	No 16ga.	¾"		Nails for Laths
14	¼x1½	4'-0"		Laths.

Above bill for 1 pair of screen doors Labor equals 6 Man Hours.

NOTE - Add 5% to items in bill and man hours labor for contingencies.

FIGURE 98.—Screen door.

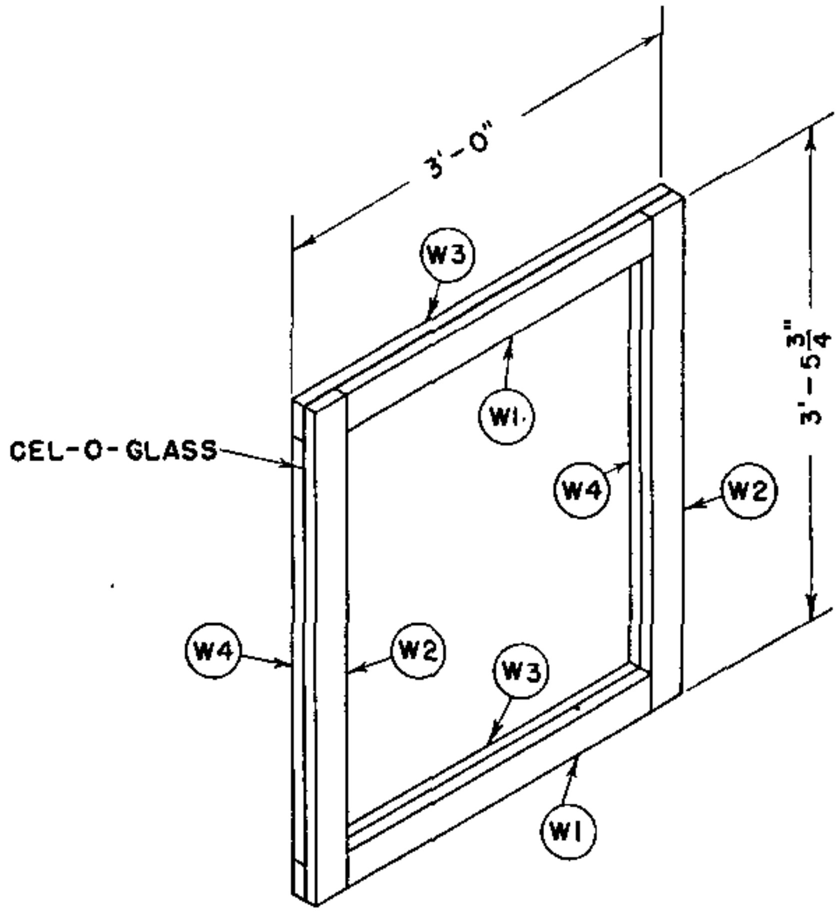


DIAGRAM OF SASH

PIECES FOR ONE SASH (24 REQUIRED)					
DESCRIPTION	MARKED	NO. PC.	SIZE	L'GTH.	APPLICATION
LUMBER	W1	2	7/8" x 3"	2'-6"	
"	W2	2	7/8" x 3"	3'-5 3/4"	
"	W3	2	7/8" x 3"	3'-0"	
"	W4	2	7/8" x 3"	2'-11 3/4"	
NAILS		4	4d	1 1/2"	W1 TO W3
"		4	4d	1 1/2"	W3 TO W1
"		12	4d	1 1/2"	W2 TO W4
"		6	4d	1 1/2"	W4 TO W2
CORNER NAILS		4	4d	1 1/2"	W1 TO W2
" "		4	4d	1 1/2"	W3 TO W4
CEL-O-GLASS			36"	41 3/4"	BETWEEN W2 & W4

FIGURE 99.—Details of window sash.

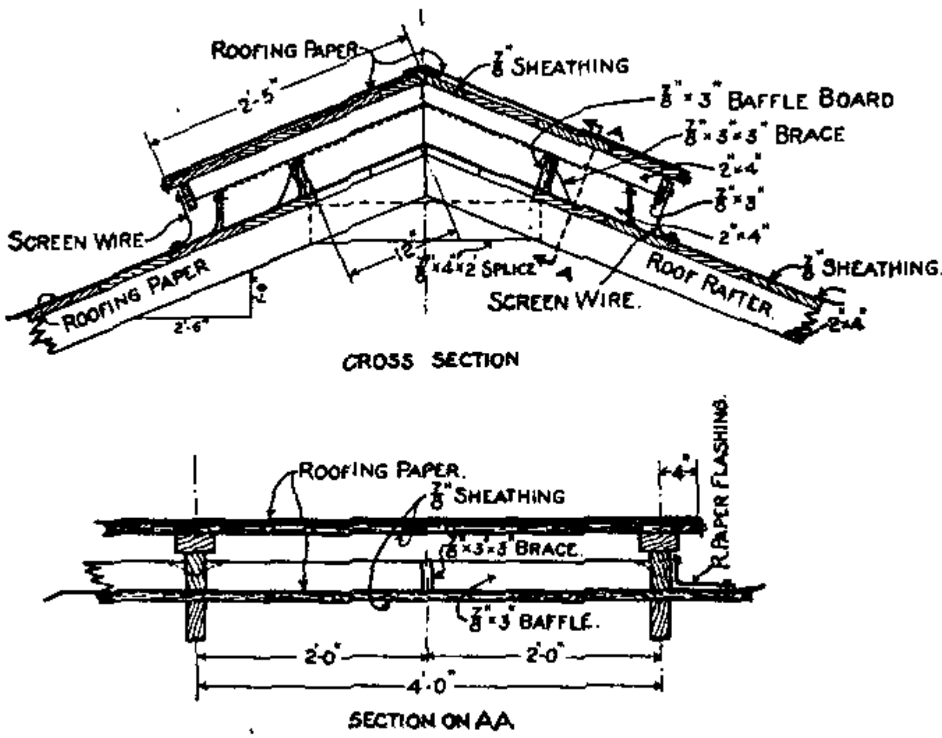
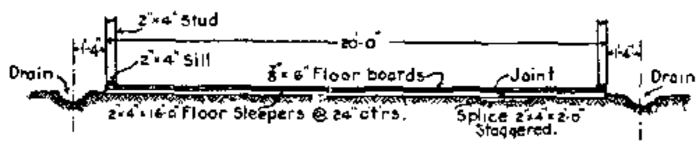


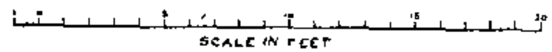
FIGURE 100.—Ridge ventilator.



CROSS-SECTION

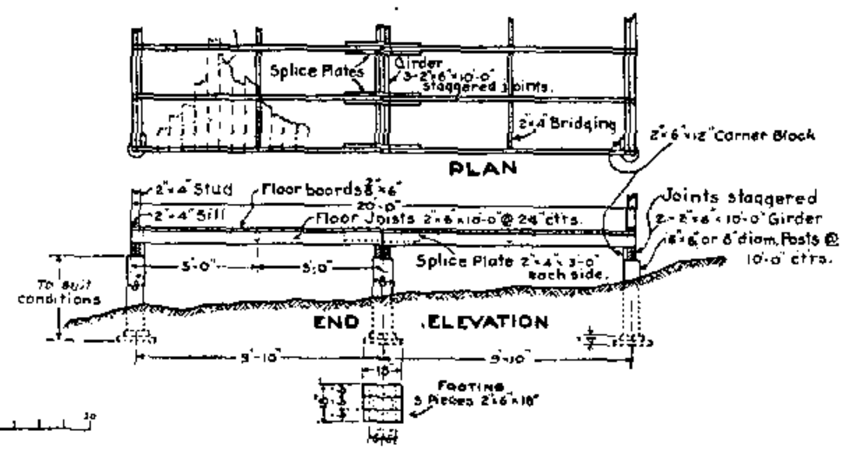
TYPE A FLOOR

Used only where the ground alone will suit.



MATERIAL FOR TYPE A FLOOR-20'×100' B'LDG.				
No. Pcs.	Size	Lgth.	Ft. B.M.	Items.
288	7/8×6	16-0"	2304	Floor Boards
67	2×4	16-0"	715	Sleepers
42 lbs.	8 d.	2½"		Nails
4 lbs.	20 d.	4"		Nails

5% has been added to above figures not including waste, which is taken at 10% (Flooring).
LABOR = 90 Man Hours.



Designed for 40 lbs per square foot.

TYPE B FLOOR

Used only where the ground is unsuited for TYPE A FLOOR.

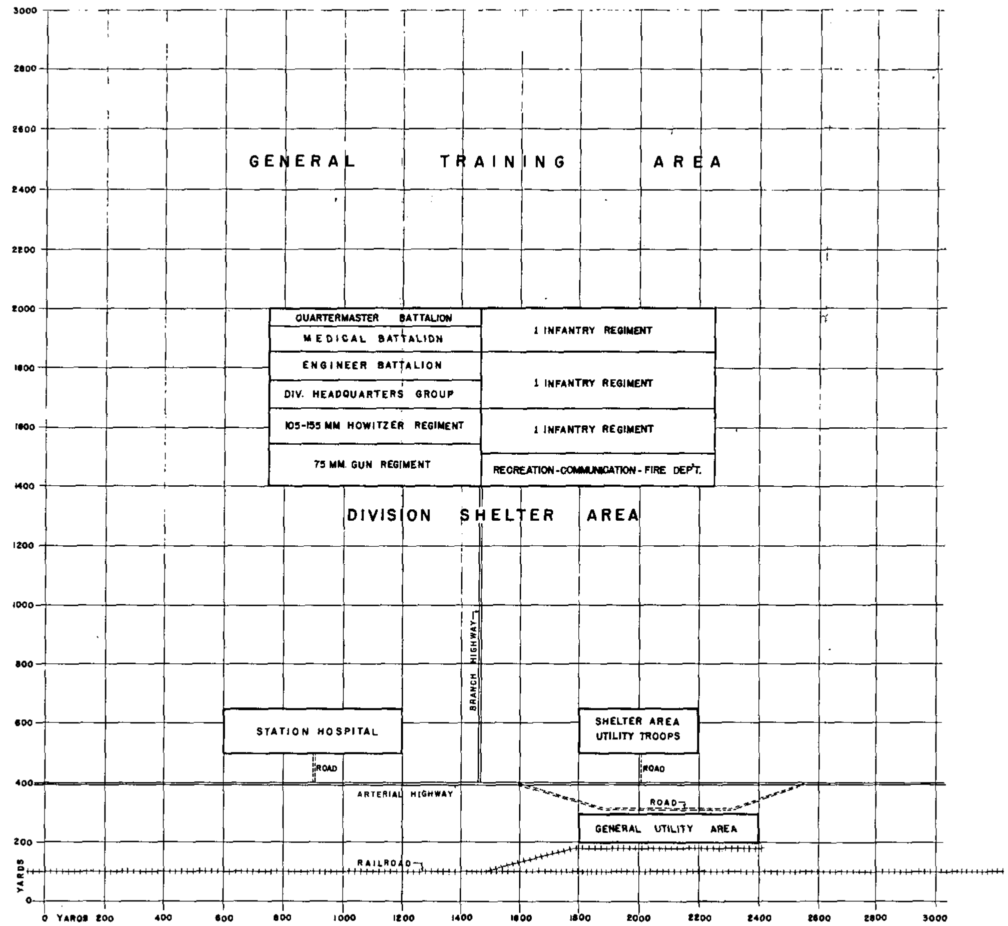
MATERIAL FOR TYPE B FLOOR-20'×100' B'LDG.				
No. Pcs.	Size	Lgth.	Ft. B.M.	Items.
288	7/8×6	16-0	2304	Floor Boards
107	2×6	10-0"	1070	Joists
21	2×4	10-0"	140	Bridging
27	2×4	12-0"	216	Splices
3	2×6	10-0"	30	Splices
36	8" dia.	To suit conditions		Posts. Note: 6"×6" may be used.
21	2×6	12-0"	252	Footing
6	2×6	1-0"	6	Corner Blocks
73	2×6	10-0"	730	Girders
39 lbs.	8 d.	2½"		Nails
85 lbs.	20 d.	4"		Nails

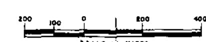
5% has been added to above figures not including waste, which is taken at 10% (Flooring).
LABOR = 320 Man Hours.

FIGURE 101.—Floors.

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY





WORK PROJECTS ADMINISTRATION OFFICIAL PROJECT 65-2-97-20

SCHEDULE OF BUILDINGS

—NOTES—

1 *Anti-Aircraft locations to be determined at the site.*
2 *Electricity and water:commercial sources to be utilized if practicable.*
3 *General utility area will include necessary supply and repair facilities*
4 *Recreational area will include the following: Chapel, Red Cross, Gymnasium, Theater and Post Exchange.*
5 *Communications area will include the following: Mail, Telephone, Telegraph, Teletype, Wireless (Radio) and Press Building.*
6 *Existing Road Net to be utilized to fullest possible extent.*
7 *Location of areas and installations indicated will be dependent upon local terrain.*
8 *The characteristics of the terrain will be utilized to the best advantage in the application of protective concealment.*
9 *The general training area will include facilities for training in the use of infantry and artillery weapons, and for training in the use of gas protective devices.*

REV. NO.	DATE	REVISION	APP. BY	APP. O.C.E.

(Face p. 298—No. 1)

① Limited dispersion lay-out.

FIGURE 102.—Cantonment, triangular infantry division.

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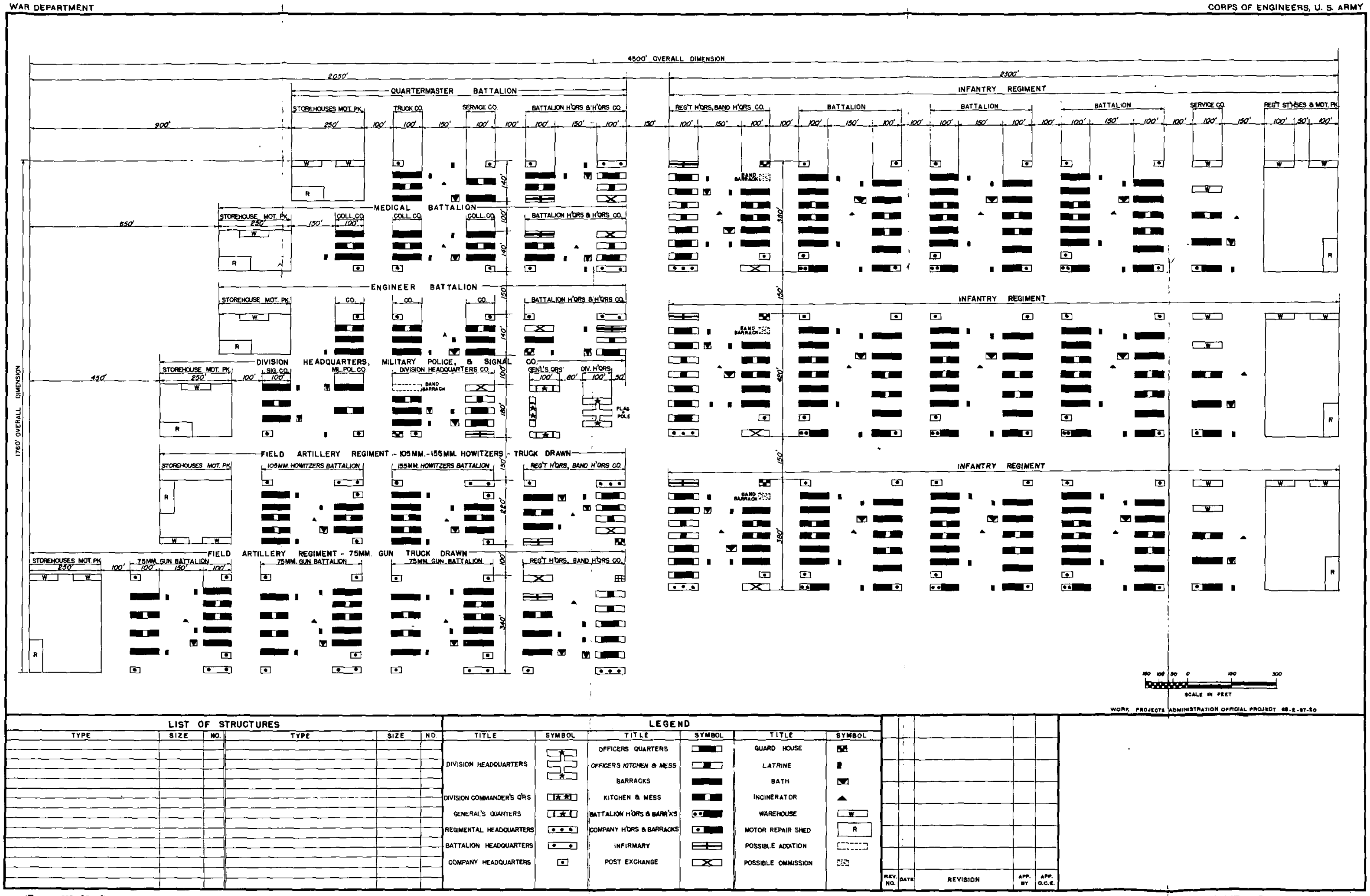


(Face p. 298—No. 2)

U. S. GOVERNMENT PRINTING OFFICE : 1940—O-248037

① Unit area lay-out.

FIGURE 102.—Cantonment, triangular infantry division.

■ 182. LAYOUT OF SEMIPERMANENT CAMPS.—*a. Requirements.*—Structural requirements for semipermanent camps for units for various arms will depend upon the current Tables of Organization. Facilities needed in every semipermanent camp are barracks, messes, latrines, baths, lavatories, administration building, medical building, guardhouses, storehouses, post exchange, officers' mess, and officers' quarters. Units having motors require shops; units having animals require stables, corrals, and watering troughs. One recreation building per regiment or independent battalion is conducive to good morale. Tents may be used in place of barracks. Local facilities, especially roads, should be used to avoid unnecessary construction. Kitchens, hospitals, warehouses, stables, motor parks, and offices should be accessible by roads. Stables, incinerators, and latrines should be located where prevailing winds will carry annoying odors away from the camp. Latrines should be located as far away from kitchens as practicable to lessen the fly nuisance. A compact layout is preferable, but provision should be made for future possible expansion. Water-bearing fire preventive systems are too expensive to be used; chemical carts are practicable. Figure 102 shows a typical semipermanent camp layout for a triangular infantry division.

b. Rule of thumb.—A rough rule for determining the area of a semipermanent camp for any unit is as follows:

50 square yards per man.
60 square yards per animal.
150 square yards per vehicle.

To use the rule, multiply each unit figure by the corresponding number of men, animals, and vehicles in the unit, and add the products. Application of this rule to Tables of Organization gives the data tabulated below. To this total must be added the area needed for general supply, training, station hospital, railroad yards, etc. The figures also apply approximately to tent camps where space is available for erection without crowding.

TABLE XLVIII.—*Approximate areas required for semipermanent barrack camps for the square infantry division, peace and war strength*

Unit	Area (acres)	
	Peace strength	War strength
Division headquarters and special troops	10.5	15
Infantry brigade headquarters and headquarters company	1	1
Infantry regiment	23	31
Infantry brigade	47	65
Headquarters and headquarters battery, field artillery brigade	1.5	1.5
Field artillery regiment (75-mm gun, horse-drawn)	32	33
Field artillery regiment (75-mm gun, truck-drawn)	20	21
Field artillery regiment (155-mm howitzer)	26	27
Field artillery brigade	80	83
Engineer combat regiment	11.5	12.5
Medical regiment	8.5	15
Quartermaster regiment	16	25
Total for a division (exclusive of division aviation and landing field)	175	216

TABLE XLIX.—*Approximate areas required for semipermanent barrack camps for the triangular infantry division, peace strength*

Unit	Area (acres) peace strength
Division headquarters	1.5
Headquarters and military police company	3
Signal company	4
Engineer battalion	5
Medical battalion	4
Quartermaster battalion	7
Field artillery regiment (75-mm gun)	26
Field artillery regiment (155-mm howitzer)	15
Infantry regiment, each (3)	24
Total for a division	138

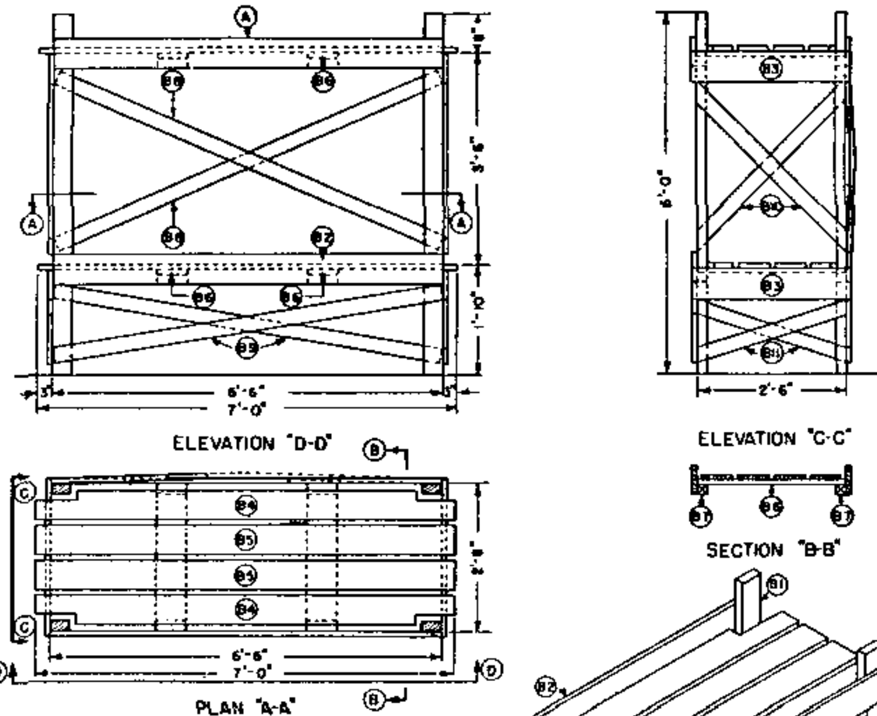
TABLE L.—*Approximate areas required for semipermanent barrack camps for certain units of the cavalry division, peace and war strength*

Unit	Area (acres)	
	Peace strength	War strength
Cavalry regiment, horse	20	44
Engineer squadron	6.5	6.5
Field artillery regiment (75-mm field howitzer, horse)	34	35

■ 183. BARRACKS.—In the theater of operations, a fair assumption is that barracks will have to be provided for 60 percent of the total force plus 100 percent of the prisoners. In any particular camp, barracks must be provided for all of the troops, and may have to be provided for civilian labor. Barrack space is provided on a basis of 50 men per standard building, 20 by 100 feet. An air space of 400 cubic feet per man is required as a minimum. One hundred men per standard building, 20 by 100 feet, can be sheltered in emergencies, but this is undesirable from a health standpoint. Bunks, of the double-decker type where space is scarce, should be provided for all men. Figure 103 shows a bunk for two men.

Figures 104 and 105 show tent frames for various types of tents suitable for personnel shelters.

248037°—40——20



PIECES FOR ONE TWO-MAN BUNK
(23 REQUIRED)

DESCRIPTION	MARKED	NO PC	SIZE	LGTH	APPLICATION
LUMBER	B 1	4	2"x4"	6'-0"	
"	B2	4	7/8"x6"	6'-6"	
"	B3	4	7/8"x6"	2'-7½"	
"	B4	4	7/8"x6"	7'-0"	
"	B5	4	7/8"x6"	7'-0"	
"	B6	4	7/8"x6"	2'-6"	
"	B7	8	2"x2"	6"	
"	B8	2	7/8"x3"	7'-0"	
"	B9	2	7/8"x3"	6'-7½"	
"	B10	2	7/8"x3"	3'-10"	
"	B11	2	7/8"x3"	2'-8"	
NAILS		32	8d	2½"	B2 to B1
"		24	8d	2½"	B3 to B1
"		24	6d	2"	B8 & B9 to B1
"		16	6d	2"	B10 & B11 to B1
"		8	6d	2"	B6 to B7
"		24	6d	2"	B2 to B7
"		16	3d	1¼"	B4 & B5 to B6
"		16	3d	1¼"	B4 & B5 to B3
"		2	3d	1¼"	B8 to B9

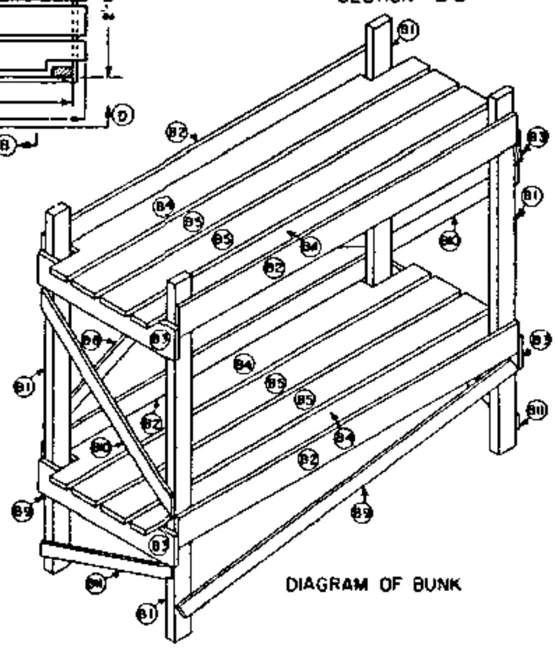
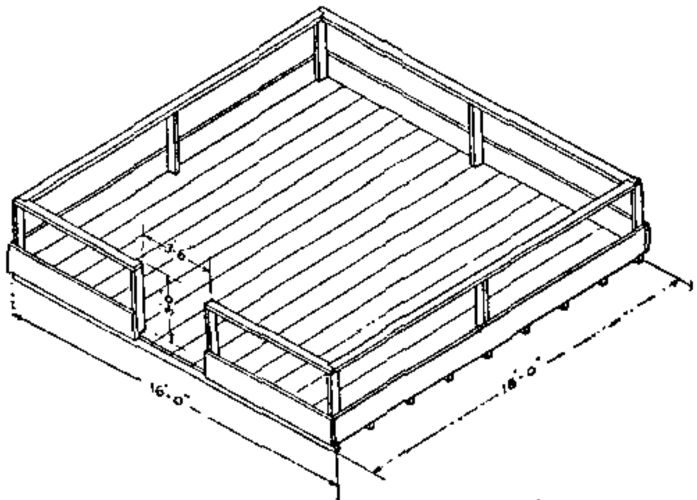


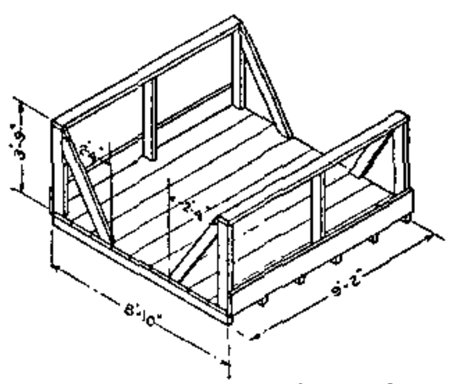
FIGURE 103.—Bunk for two men.



PYRAMIDAL TENT FRAME (LARGE)

BILL				
No Pcs.	Size	L'gth	Ft BM.	Items
9	2"×4"	16'-0"	96	Floor Sleepers
	6,8 or 10"		256	Floor Boards S 1 S & 2 E. 1" Lumber.
3 lbs				Nails for Floor.
4	2"×4"	16'-0"	43	Railing
3	2"×4"	10'-0"	20	Posts
4	1"×12	16'-0"	64	Skirt Boards.
3 lbs	20 d	4"		Nails for Framing.
1 lb	10 d	3"		" " "

LABOR: 24 MAN HRS.

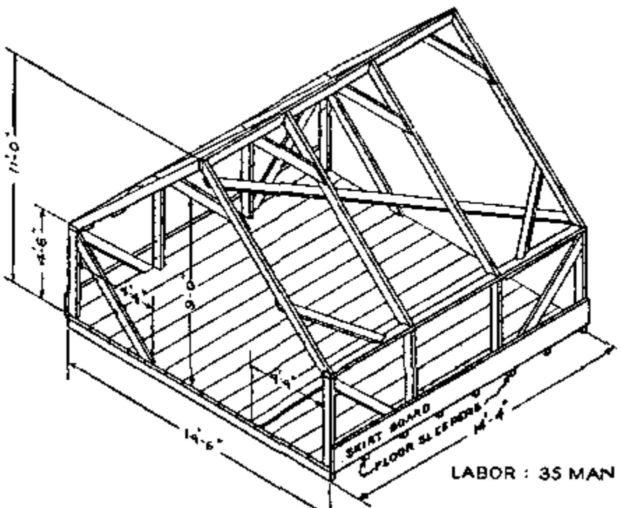


WALL TENT FRAME (SMALL)

BILL				
No Pcs.	Size	L'gth	Ft BM.	Items
6	2"×4"	10'-0"	40	Floor Sleepers.
	6,8 or 10"		81	Floor Boards S 1 S & 2 E. 1" Lumber.
2 lbs	8 d	2½"		Nails for Floor
2	2"×4"	10'-0"	13	Railing.
2	"	12'-0"	16	Posts
2	"	10'-0"	13	Braces
2	"	10'-0"	13	Skirt Boards.
2 lbs	20 d	4"		Nails for Framing.
1 lb.	10 d.	3"		" " "

LABOR: 10 MAN HRS.

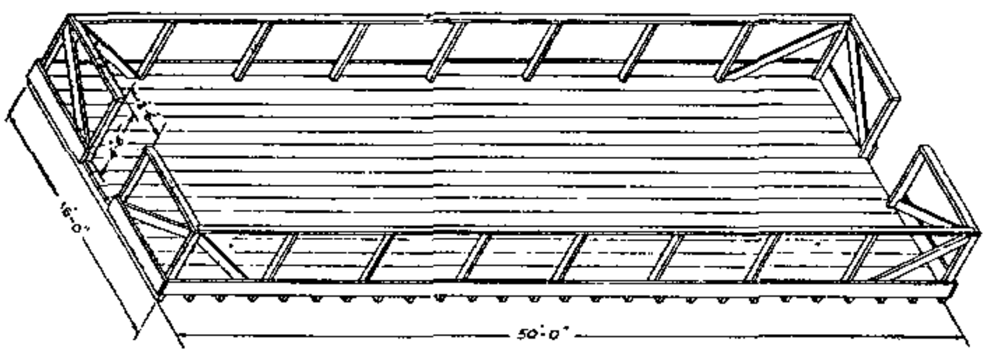
FIGURE 104.—Pyramidal and small wall tent frames.



LABOR : 35 MAN HRS.

WALL TENT FRAME (LARGE)

BILL				
No Pcs.	Size	L'gth	Ft B.M.	Items
8	2"x4"	16'-0"	85	Floor Sleepers.
	6.5x10'		208	Floor Boards, S1S & 2E, 1" Lumber.
4 lbs	8 d.	2½"		Nails for Floor.
10	2"x4"	10'-0"	67	Roof Rafters and Ties
3	"	16'-0"	32	Ridge Board and Rafter Plates
2	"	18'-0"	24	Posts.
2	1"x6"	16'-0"	16	Long Braces on Rafters.
2	1"x6"	12'-0"	12	Short Braces " "
4	2"x4"	14'-0"	37	Braces at Posts.
2	1"x12"	16'-0"	32	Skirt Boards
4 lbs	20 d	4"		Nails for Framing
1 lb	10 d	3"		" " "

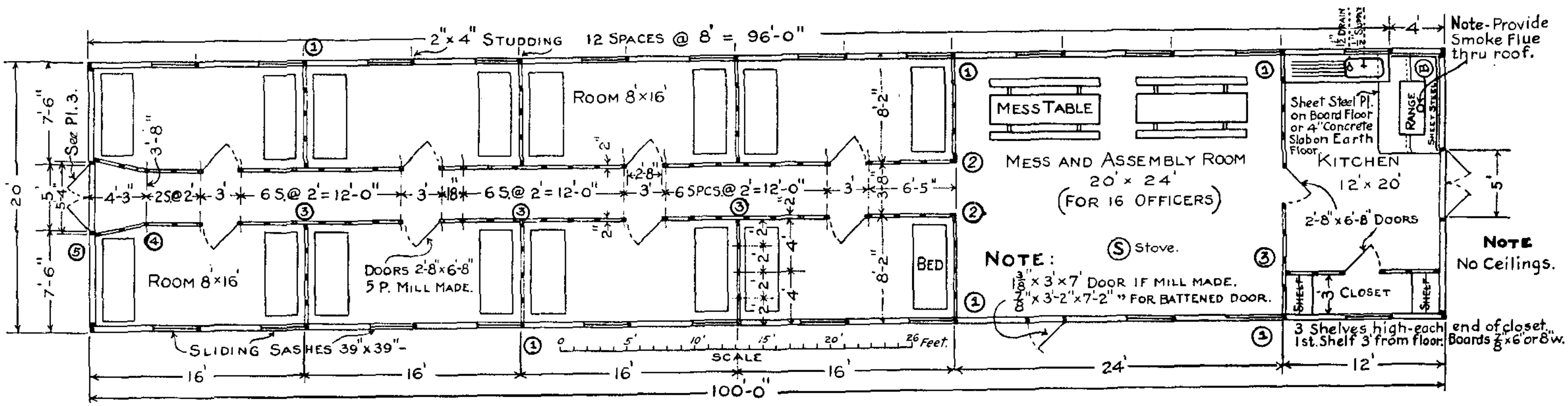


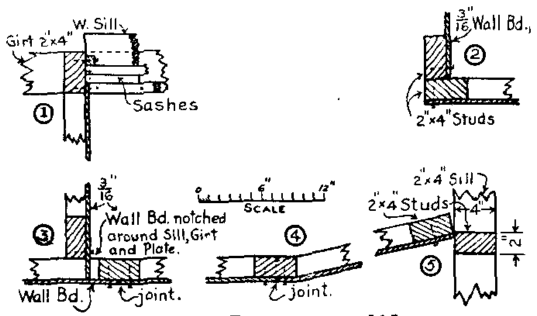
HOSPITAL WARD TENT FRAME

BILL				
No Pcs.	Size	L'gth	Ft B.M.	Items
25	2"x4"	16'-0"	277	Floor Sleepers
	6.8x16'		800	Floor Boards, S1S & 2E 1" Lumber
15 lbs	8 d	2½"		Nails for Floor.
10	2"x4"	14'-0"	93	Railing.
6	"	16'-0"	72	Posts.
4	" "	16'-0"	43	Braces
10	1"x12"	14'-0"	140	Skirt Boards.
5 lbs	20 d.			Nails for Framing
4 lbs	10 d.			" " "

LABOR : 64 MAN HRS.

FIGURE 105.—Large wall and hospital ward tent frames.

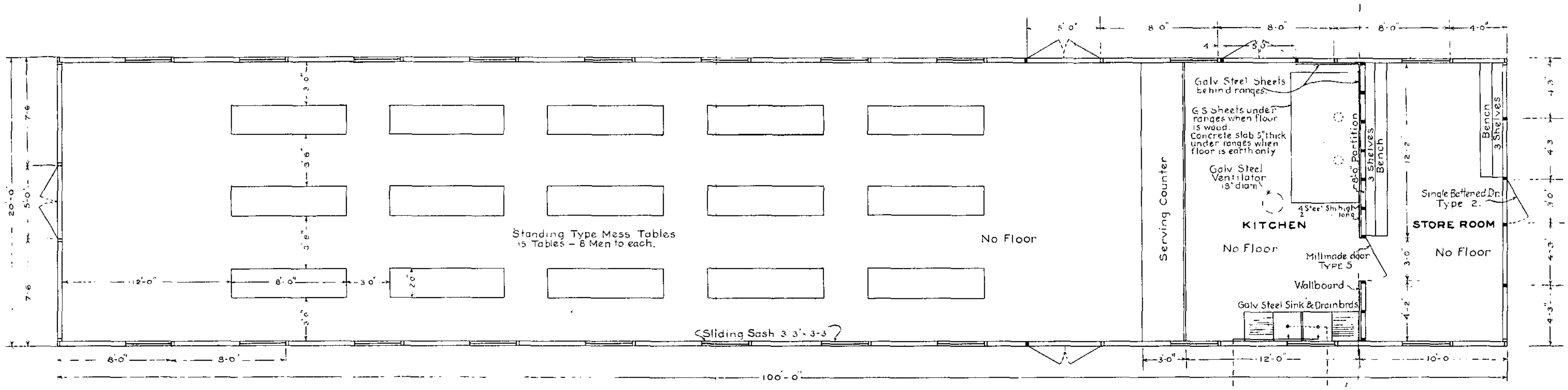




Details of Partition Work

Material for Partition Work Only Material for St'd. 100 Ft. Bldg					
Nº Pcs.	Size	Length	Ft. BM.		Items
102	2"x4"	16'	1088	982	Studs, Girts, Sills, Plates, Ties and Stakes.
8	2"x6"	16'	144	128	Foundation Blocks. 12" and 18" Lengths.
59	48" w.	10'			Wall Board Sheets, Fibre 3/16" thick.
7	2 d.	1"			Nails, Large Headed for Wall Board. 8" Spacing.
10	1⅜x2-8	6'-8"			Doors, 5 Panels W. Pine-Mill Made.
10	3¼"	4"			Locks, Rim; with Pottery knobs, Strikes, etc.
20	4"x4"	4"			Hinges for Doors, Steel Fast Joint with Screws.
15	⅞x⅞"	16'	20	19	Door Stop Strips.
3	4 d.	1½"			Nails for Door Stop Strips.
16	10 d.	3"			Nails for Partition Framing.
3	⅞x6 or 8"	12'	24	24	Shelves, Kitchen Closet.
3	⅞"x8"	8'	16	16	Drain Board for Sink.
1	18"	30"			Sink, Cast Iron. with Strainer and Trap.
1	½"	12'			C.W. Supply Pipe, W.I. Galv.
1	½"				Bibb, Plain for C.W. Supply. Comp.
1	1½"	12'			Drain Pipe - Black W.I.
3	28" w.	84"			Sheet Steel, Galv. for behind Range.
2	28" w.	84"			Sheet Steel Hearth. -
1	4"x4'-6	7'	11 Cu. Ft.		Concrete Hearth Slab-

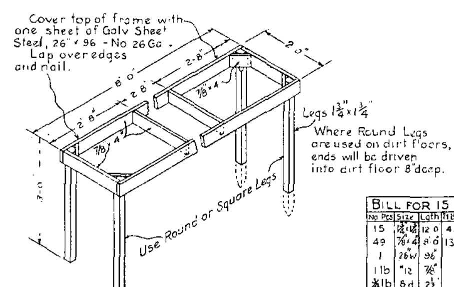
Figure 106.—Standard building adapted for officers' quarters and mess.



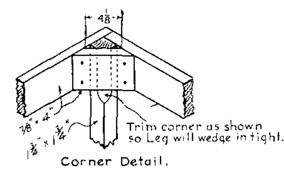
PLAN

KITCHEN AND MESS HALL

~ Capacity 120 men. ~



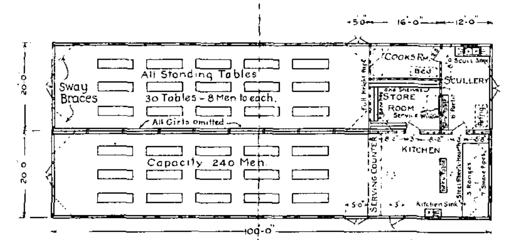
Bill for 15 Standing Tables				
No Pcs	Size	Lgth	FBM	Items
15	1¾" x 1¾"	12'0	45	Legs.
49	⅞" x 4"	8'0"	131	Frame & Corner Braces
1	26"w	96"		Sheet Steel, Galv (for Top)
1 lb	"12	⅞"		Nails, Roofing, Barbed
¾ lb	8d	2½"		Nails for Framing.
15	2 ø	14'0		Round Legs if used



Corner Detail.

STANDING TABLE

Labor: 1½ Man Hrs.



PLAN OF MESS HALL
CAPACITY 240 MEN
(2-20' x 100' Buildings joined together)

FIGURE 107.—Standard building adapted for kitchen and mess.

(Face p. 304)

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■ 184. OFFICERS' QUARTERS.—The standard building is adapted for officers' quarters by partitioning off double rooms 8 by 16 feet. A messroom and kitchen may be installed at one end, as shown in figure 106.

■ 185. KITCHEN AND MESS HALLS.—Figure 107 shows the standard building adapted for use as a mess hall suitable for 120 men. A space 20 by 12 feet at one end suffices for the

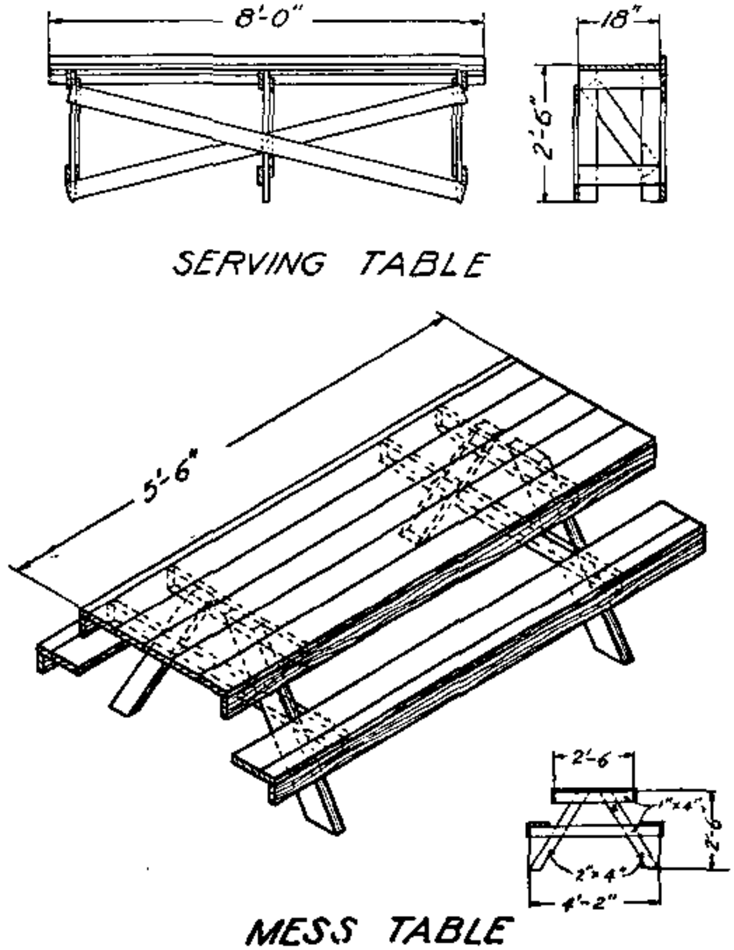


FIGURE 108.—Mess hall accessories.

kitchen. Two buildings 20 by 100 feet can be combined to give a mess hall suitable for 240 men.

Figure 108 shows a mess table combined with seats, and a serving table.

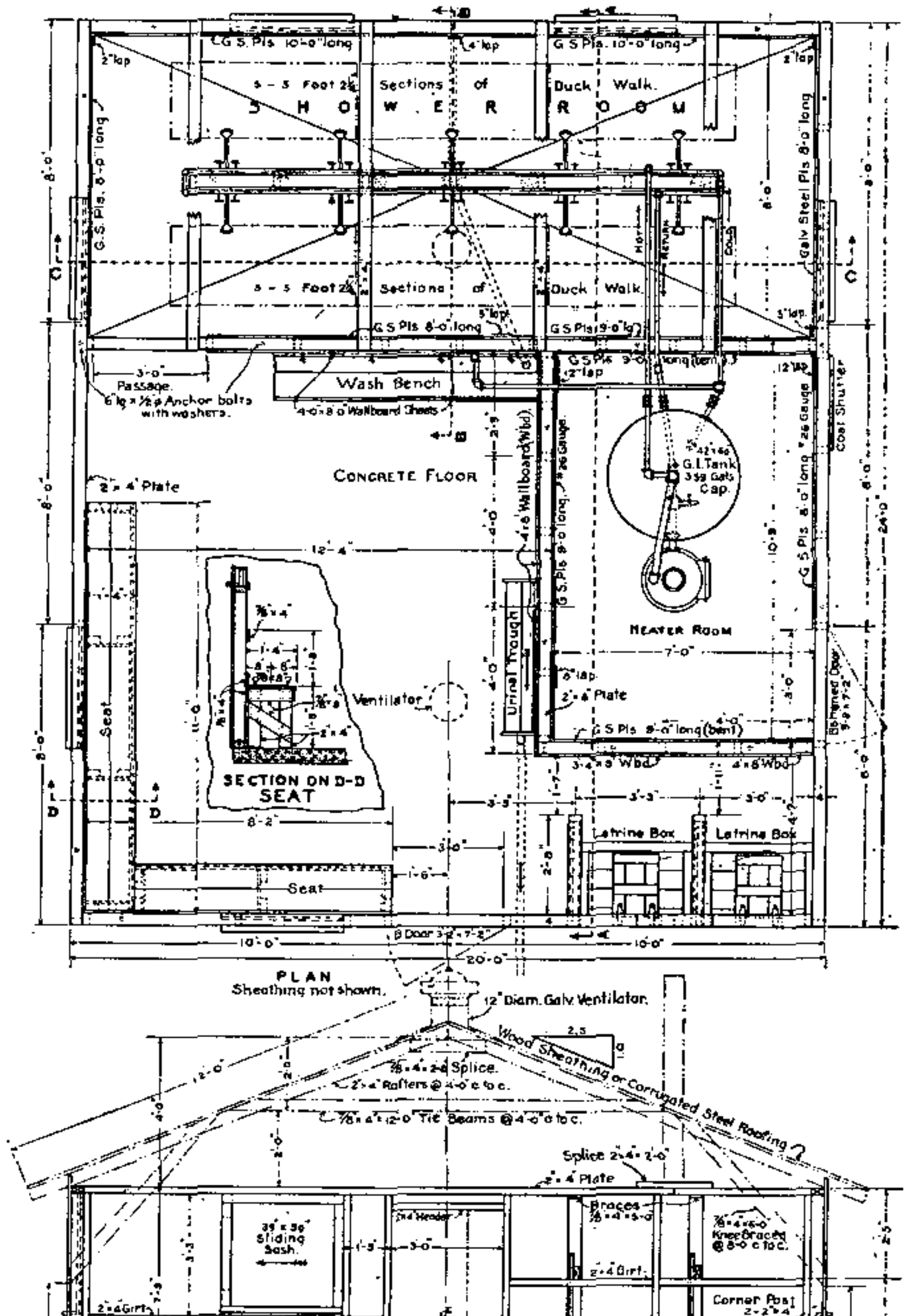
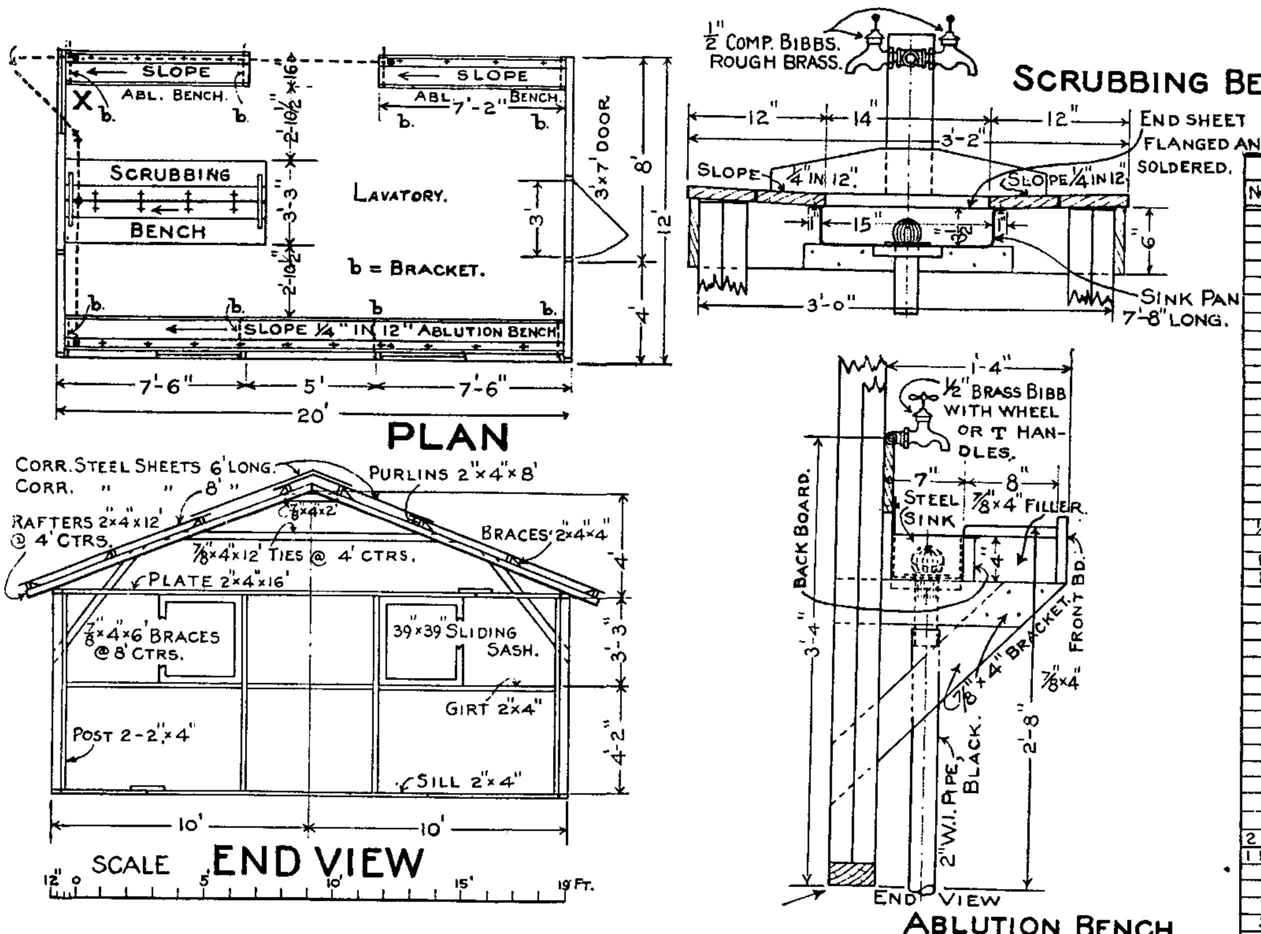


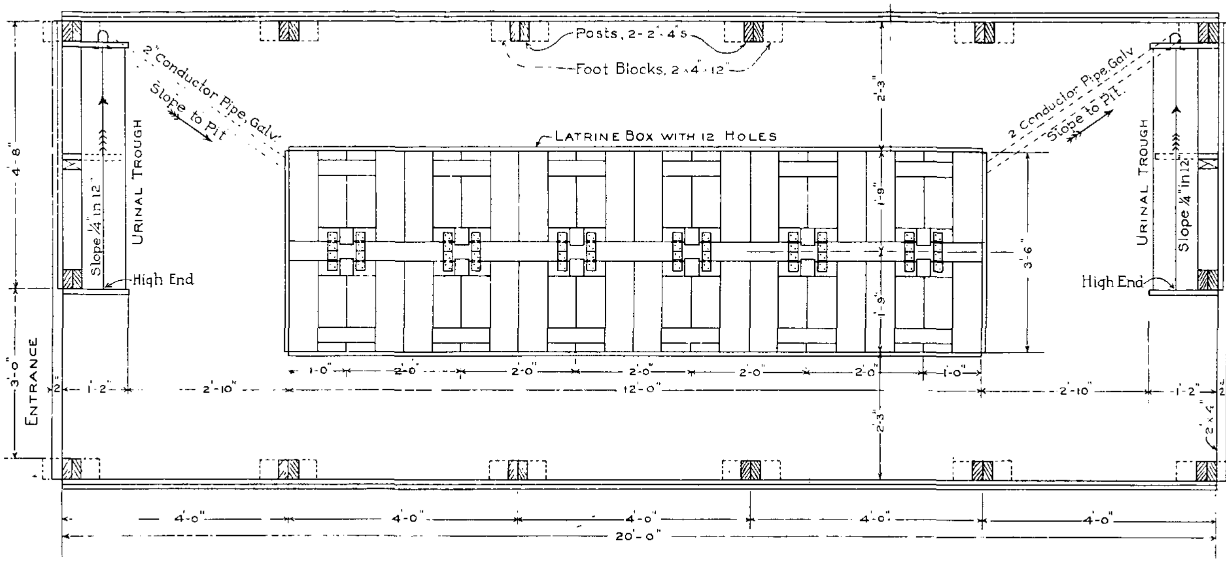
FIGURE 109.—Bathhouse and lavatory (company).



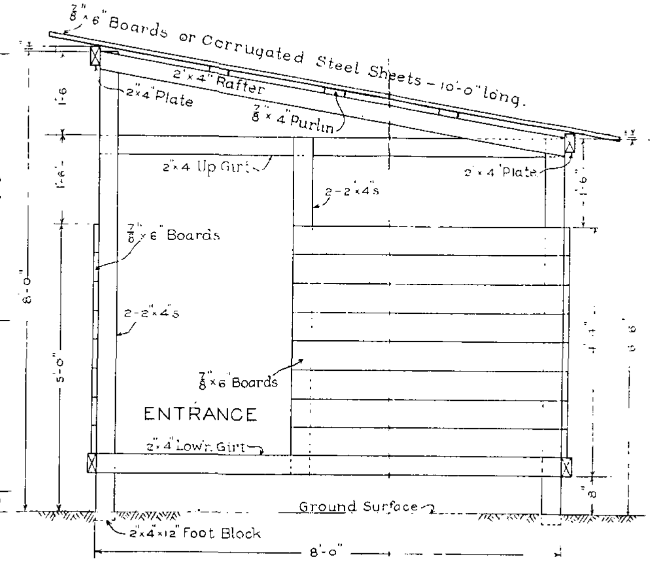
MATERIAL FOR LAVATORY				
No. Pcs.	Size	Length	Ft. B.M.	Items.
27	2"x4"	16'	288	SILLS, GIRTS, PLATES, STUDS, PURLINS,
		SUB-SILLS,		PUR. BRACES, SPLICES, & FLR. JOISTS.
16	2"x4"	12'	128	RAFTERS, BENCH LEGS, PIPE SUP. & FL. JOI. SPLS.
35	7/8"x8"	12'	280	FLOOR BDS, ABLUTION BENCH TOP & SASH CORNERS.
4	7/8"x6"	14'	28	DOOR, BOARD.
20	7/8"x6"	8'	80	ABL. & SCRUB. BENCHES & BDS. OVER WINDOWS
13	7/8"x4"	8'	35	ABL. & SCRUB. BEN. & ABL. BEN. BRACKETS.
5	7/8"x4"	12'	20	RAFTER TIES & KNEE BRACES.
4	7/8"x3"	12'	12	SILLS & SASHES, WINDOW.
1	7/8"x1 3/4"	10'	1 1/2	WINDOW FILLERS.
8	7/8"x 1"	14'	10	STRIPS FOR DOOR & WINDOWS.
2		10"		T HINGES WITH SCREWS-STEEL.
2		3"		SCREW HOOKS & EYES.
12	26" W.	8'	BLACK	CORR. STEEL SHEETS #26 GA. FOR ROOF.
12	"	6'	"	" " " " " " .
27	"	8'	"	" " " " SIDES & END
1	24" W.	8'		STEEL SHEETS, GALV. #26 GAUGE.
3	36" W.	8'		" " , " " " .
1/2 lb.	3/16"	3/8"		RIVETS FOR CORR. STEEL SHEETS.
2 lbs.	#10	1 1/2"		NAILS, BARBED, FOR ROOFING.
12 lbs.	20 d.	4"		" FOR FRAMING WORK.
10 lbs.	8 d.	2 1/2"		" FOR 7/8" STUFF.
1 lb.	4 d.	1 1/2"		" FOR WINDOW STRIPS & DOORS.
4	3/4"	12' TO 16'		W. I. PIPE, GALV. FOR SUPPLY.
2	1"	" - "		" " , " . " " .
1	1 1/2"	" - "		" " , " . " " .
	2"	40 LIN. FT.		" " , BLACK " WASTE.
4	3/4"			ELBOWS. FOR SUPPLY. GALV.
2	1"x3/4"			" . " " . " .
1	1 1/2"			" . " " . " .
1	2"	45°		" . " WASTE. " .
4	3/4"x1/2"			CROSSES. " .
18	3/4"x1/2"			TEES. " .
2	1"x 1"			" . " .
4	2"			" . " .
1	3/4"			CAP. " .
2 EACH	2"&3/4"			PLUGS. " .
1 EACH	1"&3/4"			UNIONS. " .
1	1/2" TO 1"			REDUCER. " .
12	1"			PIPE STRAPS, TINNED.
1	1 1/2"			STOP & WASTE COCK-LEVER HANDLE.
36	1/2"			COMPRESSION BIBBS, ROUGH BRASS.
4	2"	6"		THIMBLE, COMPLETE WITH WIRE STRAINER
1 LB.				ROOFING CEMENT FOR THIMBLES.

FIGURE 110.—Lavatory with benches.

248037°—40 (Face p. 306)



SECTIONAL PLAN



END ELEVATION

Entrances to be screened with burlap or brush screens, when necessary.

NOTE-Omit "Prepared Roofing" if Cover Strips are used.

BILL FOR LATRINE SHELTER-WOOD ROOF				
No Pcs	Size	Length	Ft BM	ITEMS
34	2"x4	8'-0"	181	Studs U.&L.End Girts & Foot Blocks.
6	2"x4"	10'-0	40	Roof Rafters
8	2"x4"	12'-0	64	Plates & Lower Girts on Sides.
20	⅞"x6"	16'-0"	160	Sheathing on Sides.
49	⅞x6	10'-0"	245	Sheathing on Roof & Ends.
6	⅞x4"	12'-0	24	Purlins.
40	⅞x3	10'-0"	100	Strips for covering Roof joints if used.
3 Rolls	32 W			2 Ply "Prepared Roofing, Nails, Caps, Cem
6 lbs	20 d	4"		Nails for Framing
8 lbs	10 d	3"		Nails for Framing
12 lbs	8 d	2½"		Nails for Sheathing

LABOR on Shelter (wood roof) incl. 2 Urinal Troughs = 24 MAN HRS.

BILL FOR 12 HOLE LATRINE BOX				
No Pcs	Size	Length	Ft BM	ITEMS.
4	2x4"	12'-0"	32	Frame
6	⅞x8"	8'-0"	32	Cover, Top only
4	⅞x6"	12'-0	24	Lids and Two End Boards
10	⅞x4"	10'-0"	33	End Boards, Sides & Fillers.
3	⅞x3"	8'-0"	6	Lid Battens and Stop Blocks.
1 lb.	20d	4"		Nails for Framing.
½ lb.	10d	3		Nails for Framing.
5 lbs.	8 d	2½		Nails for Sheathing
1 Roll	32" W			Tar Paper for Fly-proofing, Nails, Caps, etc.
24	2" W.	3 11/16"		Hinges, Fast Joint & necessary screws.

LABOR = 22 MAN HOURS

BILL FOR TWO URINAL TROUGHS				
No. Pcs	Size	Length	Ft. B.M.	ITEMS.
1	2"x4"	6'-0"	4	Bracket Support
1	⅞"x8"	6'-0"	4	End Boards
3	⅞x6"	10'-0"	15	Trough and Splash Boards
1	⅞"x4	6'-0	2	Bracket
1 Roll	32" W.	40½'		Tar Paper, Heavy, incl Nails, Cement & Caps
½ lb.	10 d.	3"		Nails
1 lb.	8 d	2½"		Nails
2	2"			Elbows for Conductor Pipe, Galv
2	2"	2'-6"		Conductor Pipe, Galv
2	2"	4'-0"		Conductor Pipe, Galv.

LABOR = 3 MAN HOURS

BILL FOR METAL ROOF ON SHELTER IF USED				
No Pcs	Size	Length	Ft BM	ITEMS.
	27½" W	10'-0"		Corrugated Steel Sheets, No 28 Ga.
	#10	1½"		Nails Barbed Roofing.
½ lb	5/32 hole			Lead Washers.

BILL FOR TEMPORARY LATRINE SHELTER				
No Pcs	Size	Length	Ft BM	ITEMS.
14	2"x4"	10'-0"	93	Studs.
1	4'-0"	21'-0"		Canvas for Screening: or Burlap.
1	4'-0"	30'-0"		" " "

LABOR = 5 MAN HOURS

(Face p. 306)

FIGURE 111.—Latrine.

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■ 186. BATHHOUSES.—A minimum of one bathhouse per battalion area should be provided. This small allowance requires careful administration and supervision in the use of the bathhouses. One bathhouse per company, troop, or battery should be provided wherever possible. Figure 109 shows a company bathhouse and lavatory, 20 by 24 feet, constructed in a manner similar to the standard building.

■ 187. LAVATORIES.—Lavatories with ablution and scrubbing benches, as shown in figure 110, are installed at the rate of one per company whenever possible. The number of facilities depends on the water available.

■ 188. LATRINES.—Water-bearing sewerage seldom will be used. Simple latrines placed over pits generally will be provided. About one seat to 20 men is desirable, but one seat to 40 men will suffice. Figure 111 shows a standard 12-seat latrine, in a building 20 by 8 feet. If necessary, the shelter may be replaced with a simple burlap screen. Where water-bearing sewerage is installed, a simple septic tank may be constructed underground. This consists of a tank served by inlet and outlet pipes, with baffles to slow the flow. The ratio of length to width should be about 4:1, and the depth from 5 to 10 feet. Concrete is a satisfactory material. Organic matter is largely dissolved by bacterial action, and the tank requires cleaning only once or twice a year. The velocity of flow should be under 1 foot per minute. The tank capacity should be about 2 days of sewage.

For officers' and nurses' quarters a pail latrine may be used, consisting of a latrine box with removable pails underneath instead of the pit.

■ 189. SHEDS.—*a. Storage and repair shelters.*—Figure 112 shows an open-sided storage shed suitable for use where supplies are placed under the roof by hand. The roof must be raised by use of longer posts to permit vehicles to be driven underneath. This type of shed is suitable for vehicle repair work and storage of spare parts. All vehicles are stored outside. In this connection, vehicle storage areas should be graded to provide drainage. Roadways serving repair and storage areas should be surfaced, but not the storage areas themselves.

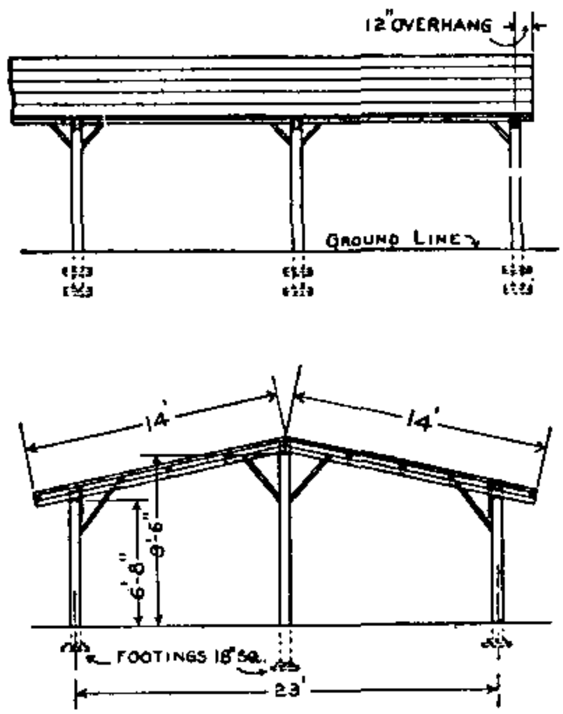

FIGURE 112.—Open-sided storage shed.

b. Animal shelters.—With mangers and feed racks installed, the open-sided storage shed makes a satisfactory horse shelter. The sides may be sheathed if necessary. Figure 113 shows this type of building, including a center grain-storage room, feed racks, mangers, and covered picket line.

■ 190. LAYOUT OF HOSPITALS.—*a. Percentage allowances.*—Total hospitalization requirements ordinarily vary between 5 and 15 percent of the total strength of the troops in the theater of operations. Prolonged fighting and unhealthful conditions may combine to necessitate total hospital provision for considerably more than 15 percent. Station hospitals at semipermanent camps should provide for hospitalization of about 5 percent of the troops in the area. The remainder of the requirement is provided in general hospitals.

b. Space.—Hospital space allowances necessarily exceed those in barracks. A minimum space at each bed of 60 square feet per patient is required. An additional minimum allowance of 30 to 35 square feet per patient should be provided for administration, supply, operating rooms, and accom-

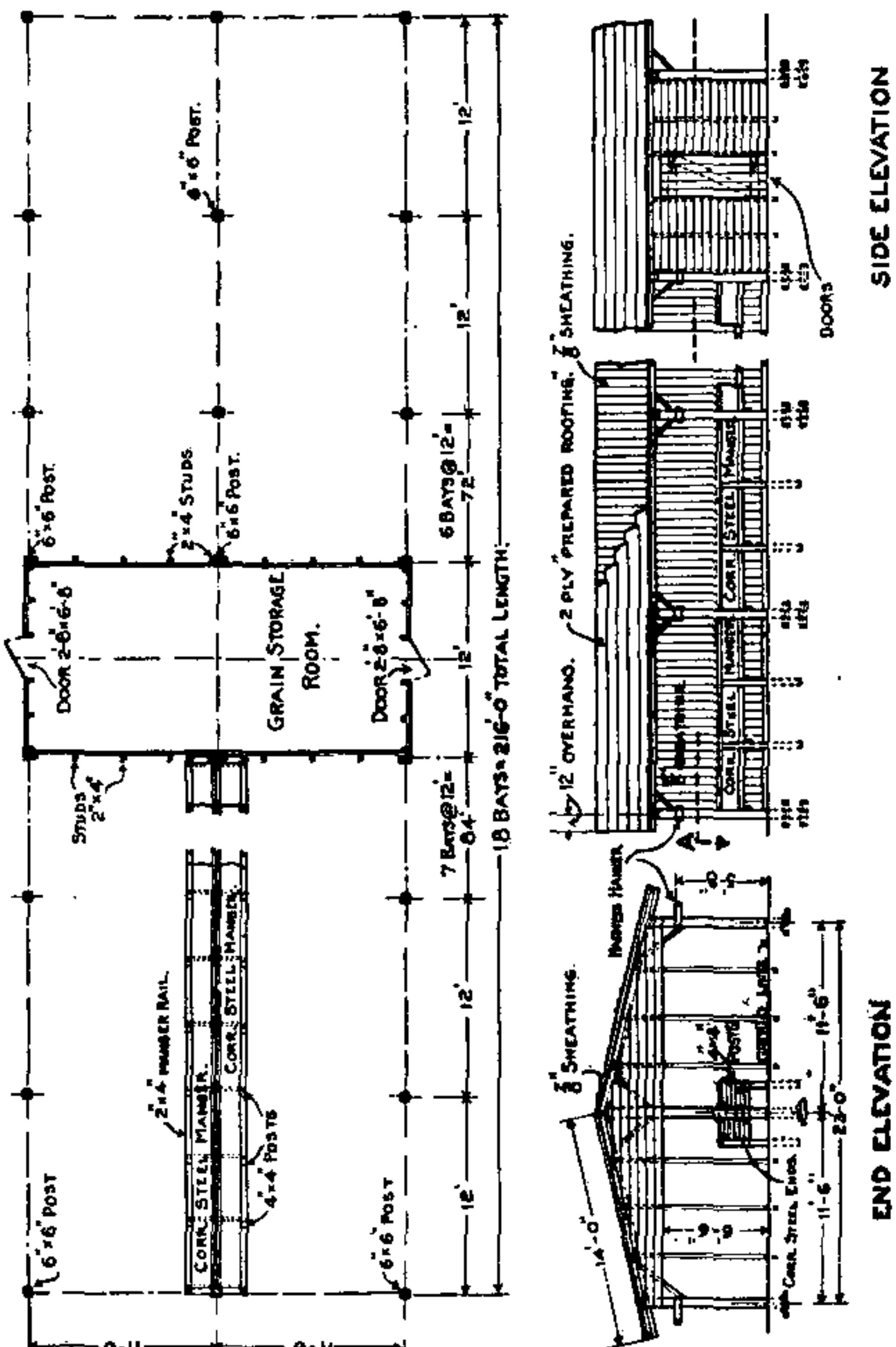

FIGURE 113.—Horse shelter.

modation of hospital personnel. General hospitals are constructed in 1,000-bed units; in emergency their capacity can be increased to 1,200 beds. Station hospitals are constructed in 250-bed units. Figure 114 shows a typical layout for a 250-bed station hospital.

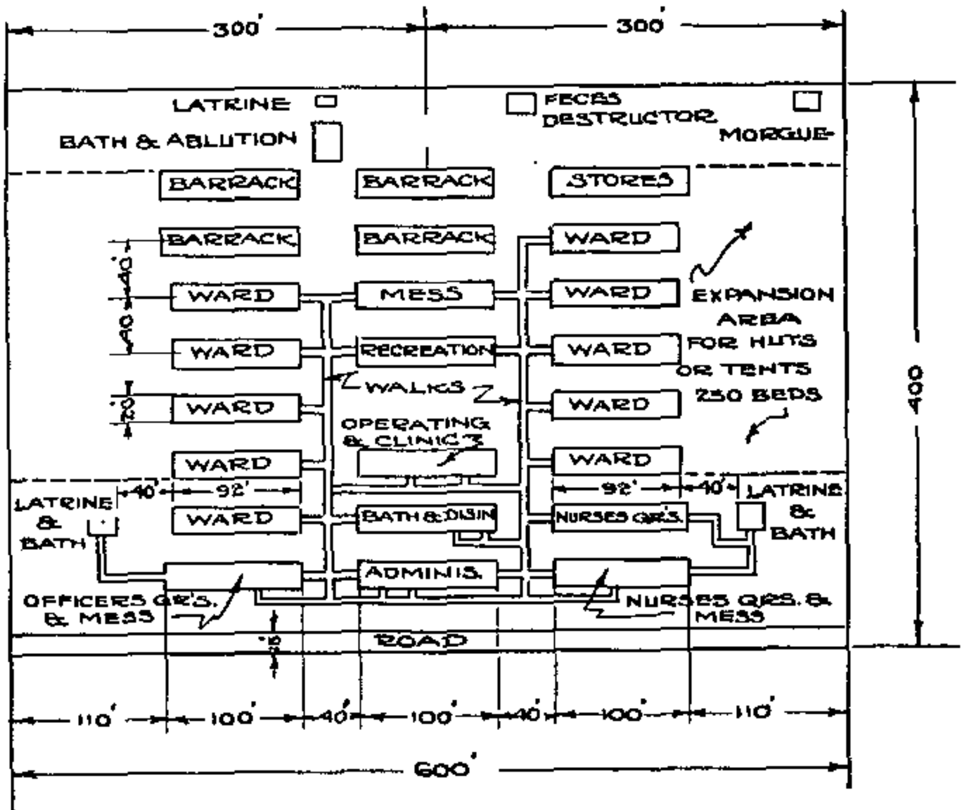

FIGURE 114.—Typical layout for 250-bed station hospital. Individual wards are constructed for normal capacities of 25 and 50 patients. Figure 115 shows the two types of wards. Table LI gives a corresponding bill of materials.

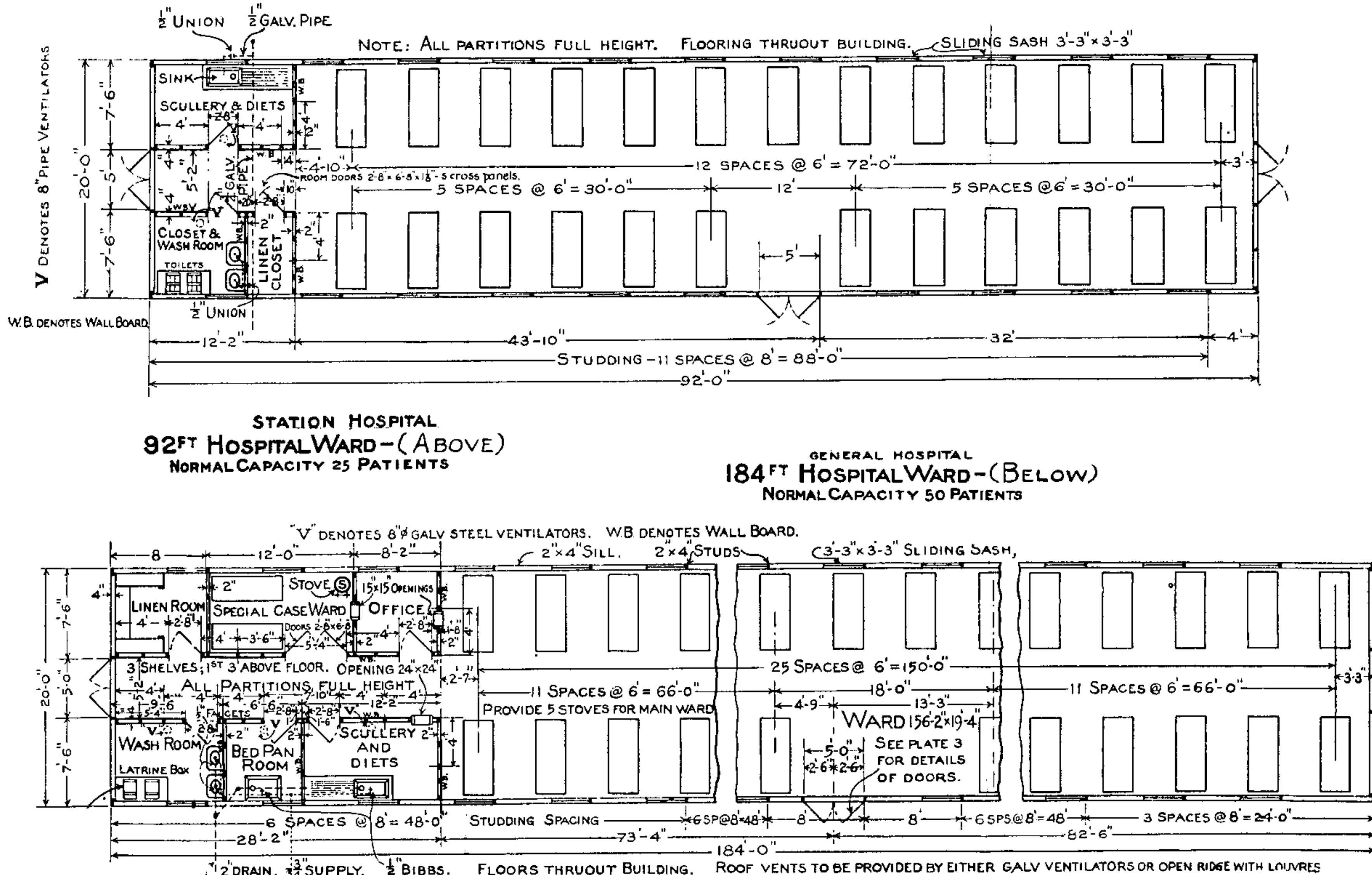

Figure 115.—Hospital wards.

TABLE LI.—*Bill of materials for standard hospital ward*

92-foot ward building, type 1, normal capacity, 25 patients				184-foot ward building, type 2, normal capacity, 50 patients				Items
Number of pieces	Size	Length	Feet, board measure	Number of pieces	Size	Length	Feet, board measure	
48	2 by 4 inches.	12 feet	384	96	2 by 4 inches.	12 feet	768	Roof rafters.
98	2 by 4 inches.	16 feet	1,012	192	2 by 4 inches.	16 feet	2,048	Framing, subrafters, and toilet box; partition studs also.
540	⅞ by 6 inches.	16 feet	4,320	982	⅞ by 6 inches.	16 feet	7,856	Sheathing, screen doors, drain board, shelves, and toilet box.
53	⅞ by 4 inches.	12 feet	212	88	⅞ by 4 inches.	12 feet	352	Rafter ties, knee braces, screen-door frames, shelves, supports, and toilet box.
12	⅞ by 3 inches.	10 feet	30	19	⅞ by 3 inches.	10 feet	48	Door meeting rails, window sills, and door bolts.
22	⅞ by 3 inches.	14 feet	77	42	⅞ by 3 inches.	14 feet	147	Sash frames.
2	⅞ by 8 inches.	16 feet	21	5	⅞ by 8 inches.	16 feet	53	Sash frames, corners.
2	⅞ by 2 inches.	10 feet	3	2	⅞ by 2 inches.	10 feet	3	Door-bolt guides.
6	⅞ by 1¾ inches.	14 feet	12	11	⅞ by 1¾ inches.	14 feet	23	Window filler strips.
42	⅞ by 1 inch.	14 feet		86	⅞ by 1 inch.	14 feet	100	Window guide strips and screen-d[illegible] strips.

TABLE LI.—*Bill of materials for standard hospital ward*—Continued

92-foot ward building, type 1, normal capacity, 25 patients				184-foot ward building, type 2, normal capacity, 50 patients				Items
Number of pieces	Size	Length	Feet, board measure	Number of pieces	Size	Length	Feet, board measure	
22	36 inches wide.	— linear feet.		46 square yards.	36 inches wide.	138 linear feet.	414 square feet.	Translucent material and 2½ ounces No. 2 tacks per 100 square feet.
24 rolls	32 inches wide.			47 rolls	32 inches wide.		5,076 square feet.	2-ply prepared roofing and nails, cement, and tin caps.
6		3 inches		6		3 inches		Hooks and screw eyes, for doors.
45 pounds	20-penny			100 pounds	20-penny	4 inches		*Framing nails.*
85 pounds	8-penny			180 pounds	8-penny	2½ inches		Sheathing nails.
3 pounds	4-penny			6 pounds	4-penny	1½ inches		Nails for strips.
1	36 inches wide.	66 linear feet.	198 square feet.	1	36 inches wide.	138 linear feet.	414 square feet.	Screen wire for windows, 14 by 14 mesh.
1	26 inches wide.	28 linear feet.	61 square feet.	1	26 inches wide.	42 linear feet	91 square feet.	Screen wire for doors, 14 by 14 mesh.
1	26 inches wide.	12 linear feet.	26 square feet.	1	26 inches wide.	*18 linear feet*	*39* square feet.	*Cellar-window wire for doors, 2 by 2* mesh.
6	¼-inch diameter.	16 inches		6	¼-inch diameter.	16 inches		Coiled wire springs with screw eyes.
12	3½ inches	3½ inches		12	3½ inches	3½ inches		Fast joint butts with screws, for screen doors.
12		10 inches		12		10 inches		T-hinges with 1½-inch screws, for *exterior doors.*
4		8 inches		4		8 inches		Strap hinges for toilet-box lids and necessary screws.

8 ounces	18 gage	½ inch		14 ounces	18 gage	½ inch		Blind staples for screen wire, windows, and doors.
16	48 inches wide.	8 feet	512 square feet.	35	48 inches wide.	8 feet	1,120 square feet.	Wallboard and 6 ounces 2-penny nails per 100 square feet.
1 roll	32 inches wide.	40½ feet	108 square feet.	1 roll	32 inches wide.	40½ feet	108 square feet.	Tar paper, 2-ply, for flyproofing toilets.
1	36 inches wide.	5 feet	15 square feet.	1	36 inches wide.	5 feet	15 square feet.	Galvanized steel sheet for toilet panf, No. 26 gage.
2	¾ inch	16 feet		2	¾ inch	16 feet		Supply pipe with coupling, galvanized.
1	2 inches	16 feet		2	1½ inches	16 feet		Drainpipe, galvanized.
3	½ inch			3	½ inch			Elbows, galvanized.
				2	¾ by ½ inch.			Elbows, galvanized.
2	¾ by ¾ by ½ inch.			2	¾ by ½ inch.			Tees, galvanized.
2	½ inch			2	½ inch			Tees, galvanized.
3	½ inch			4	½ inch			*Couplings, galvanized.*
1	¾ inch			1	½ inch			Plug, galvanized.
				1	2 inches			Plug, galvanized.
2	½ inch			3	½ inch			Unions, galvanized.
1	18 inches wide.	30 inches		1	18 inches wide.	30 inches		Cast-iron kitchen sink with strainer, trap, and cold-water composition bibb.
2	18 inches wide.	24 inches		2	18 inches wide.	24 inches		Lavatories with fittings and cold-water bibbs.
6	4 by 4 inches.	4 inches		14	4 by 4 inches.	4 inches		Steel butts with 1½-inch screws, for room doors.
3	3¼ inches	4 inches		6	3¼ inches	4 inches		Rim locks with mineral knobs.

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TABLE LI.—*Bill of materials for standard hospital ward*—Continued

92-foot ward building, type 1, normal capacity, 25 patients				184-foot ward building, type 2, normal capacity, 50 patients				Items
Number of pieces	Size	Length	Feet, board measure	Number of pieces	Size	Length	Feet, board measure	
2	¾ inch	16 feet		2	¾ inch	16 feet		Supply pipe with coupling, galvanized.
2	2 inches	16 feet		2	2 inches	16 feet		Drainpipe, galvanized.
1	2 inches			1	1½ inches			Plug.
				4	1½ inches			Elbows.
2				2	1½ inches			Tees.
				1	2 by 1½ by 2 inches.			Tees.
				3	2 by 2 by 1½ inches.			Tees.
3	1⅛ by 2 feet 8 inches.	6 feet 8 inches.		7	1⅛ by 2 feet 8 inches.	6 feet 8 inches.		Doors, 5-panel, mill-made. (Cross panels.)

CORRUGATED STEEL COVERED

94	26 inches wide.	8 feet	1,624 square feet.	186	26 inches wide.	8 feet	3,221 square feet.	Roofing, corrugated steel, No. 26 gage, black steel.
94	26 inches wide.	6 feet	1,218 square feet.	186	26 inches wide.	6 feet	2,418 square feet.	Roofing, corrugated steel, No. 26 gage, black steel.
100	2 by 4 inches.	8 feet	533	194	2 by 4 inches.	8 feet	1,035	Purlins and braces.
13	⅞ by 4 inches.	8 feet	35	25	⅞ by 4 inches.	8 feet	67	Purlin splice plates and overhang brackets.
100	26 inches wide.	8 feet	1,728 square feet.	169	26 inches wide.	8 feet	2,929 square feet.	Sides and ends, corrugated steel, No. 26 gage, black steel.
22	26 inches wide.	5 feet	238 square feet.	43	26 inches wide.	5 feet	466 square feet.	Sides, corrugated steel, No. 26 gage, black steel.
4 pounds	3/16-inch diameter.	⅜ inch		8 pounds.	3/16-1 inch diameter.	⅜ inch		Rivets, for fastening corrugated steel sheets.
5	18-inch diameter.			9	18-inch diameter.			Ventilators, galvanized steel, "economy type."
11 pounds	No. 10	1½ inches.		18 pounds	No. 10	1½ inches		Nails, barbed, for corrugated steel sheets.

TABLE LI.—*Bill of materials for standard hospital ward*—Continued

WOOD SHEATHED AND FELT COVERED

92-foot ward building, type 1, normal capacity, 25 patients				184-foot ward building, type 2, normal capacity, 50 patients				Items
Number of pieces	Size	Length	Feet, board measure	Number of pieces	Size	Length	Feet, board measure	
19 rolls	32 inches wide.	770 linear feet.	2,048 square feet.	39 rolls	32 inches wide.	1,580 linear feet.	4,212 square feet.	1-ply "prepared roofing," sides, ends, and doors.
5 bundles	¼ by 1½ inches.	4 feet		8 bundles	¼ by 1½ inches.	4 feet		Lath for sides, ends, and doors, and 12 ounces 2-penny nails per bundle.
5 rolls	32 inches wide.	203 linear feet.	540 square feet.	9 rolls	32 inches wide.	365 linear feet.	972 square feet.	2-ply "prepared roofing," with nails, tin caps, and cement, for louver.
54	⅞ by 6 inches.	16 feet	432	112	⅞ by 6 inches.	16 feet	896	Sheathing for louver roof.
22	2 by 4 inches.	10 feet	147	46	2 by 4 inches.	10 feet	307	Framing for louver.
30	⅞ by 3 inches.	12 feet	90	62	⅞ by 3 inches.	12 feet	186	Baffle boards and small brace blocks for louver.
1	8 inches wide.	180 linear feet.	199 square feet.	1	8 inches wide.	356 linear feet.	237 square feet.	Screen wire, black, and 8 ounces of ½-inch blind staples per 100 linear feet.

■ 191. WATER.—Pipe distribution of water is provided for semipermanent camps and hospitals whenever possible. This subject is discussed in chapter 7, in which section V covers pipe distribution, and section VI covers water requirements of men, animals, and engines. A general figure of 30 gallons per man and 10 gallons per animal per day is reasonable for estimates for semipermanent camps.

■ 192. ELECTRIC POWER.—Electricity is provided to a limited extent in semipermanent camps and hospitals. The subject is discussed in chapter 8, section II. For camp estimates, allow four 25-watt lights per barrack, 20 by 100 feet, and one 40-watt light per officer.

■ 193. HEATING.—All heating of wartime buildings and tents should be by stoves. Coal, wood, or gasoline may be used as a fuel, depending on which is most plentiful.

■ 194. ERECTION OF BUILDINGS.—*a. Organization.*—The following table shows a suitable organization for erection of the standard building. In a large project time generally is gained by having each detail of men work at the same operation exclusively, and carrying out the successive steps in the nature of a drill.

TABLE LII.—*Personnel for erection of standard building, 20 by 100 feet*

Operation	Number of men
1. Piers and sills	24
2. Assembly of side frames	36
3. Erection of side frames	All available
4. Assemly of side frames	9 at each end.
5. Placing rafters and knee braces	36
6. Applying sheathings	36
7. Applying roof boards	36
8. Applying composition roofing paper	36
9. Hanging doors and widows	24

b. Man-hours.—The following table gives approximate number of man-hours required for construction of various structures. These figures represent the results that may be expected of average troop labor under average conditions.

TABLE LIII.—*Approximate man-hours for construction under average conditions*

Type of construction	Man-hours
Standard barracks, 20 by 100 feet (no floor)	270
Type *A* floor	360
Type *B* floor	590
92-foot hospital ward:	
Type *A* floor	335
Type *B* floor	550
184-foot hospital ward:	
Type *A* floor	670
Type *B* floor	1,090
Mess hall, 20 feet by 100 feet (no floor)	330
Latrine, 12-seat	50
Bathhouse:	
Concrete floor	225
Wood and corrugated-iron floors	200
Open-sided storage shed (216 feet long)	300
50 bunks (2-man)	200
Camp, triangular infantry division	165,000
Station hospital, buildings only (250-bed) (fig. 114)	10,000

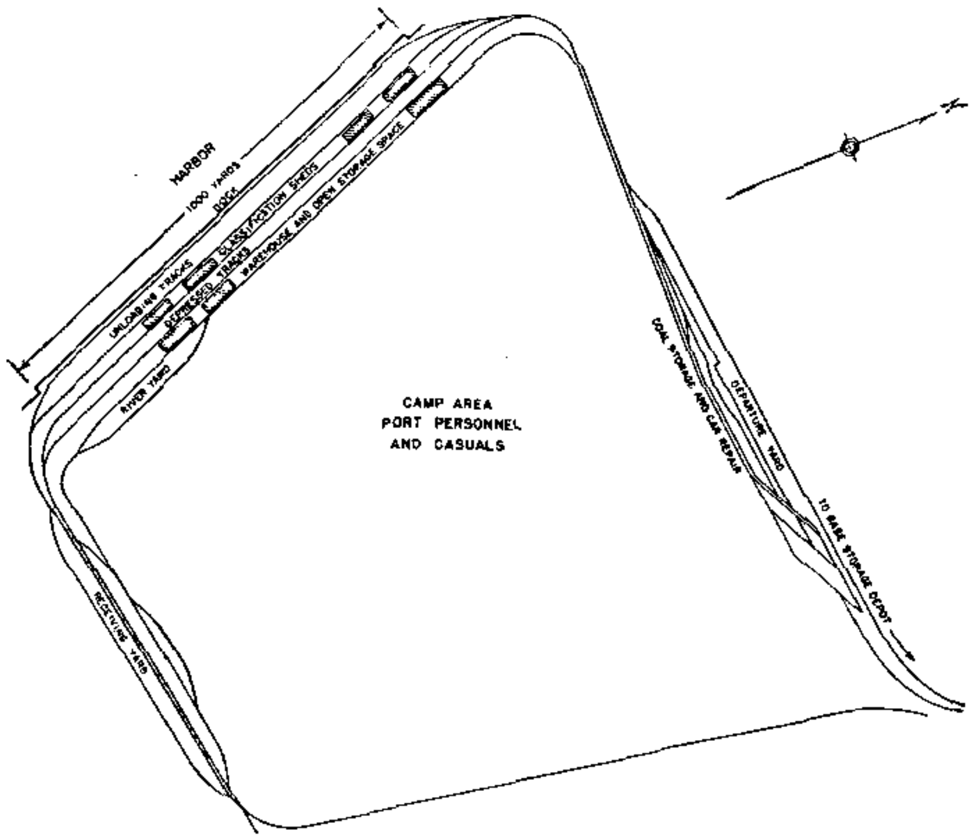
TABLE LIV.—*Unit requirements for theater of operations facilities*

Facility	Size of typical unit	Number men per typical unit	Basic ratio
1. Barrack	20 by 100 feet	50 (single bunks); 100 (double tier bunks). (in emergency)	40 square feet per man. 20 square feet per man.
2. Hospital	20 by 92 feet	25	90 square feet per man.
(all facilities)	20 by 184 feet	50	
3. Latrine	20 by 8 feet (12 seats)	240 to 480	1 seat per 20 to 40 men.
4. Bathhouse	20 by 24 feet	240	1 bathhouse per battalion area.
5. Lavatory	20 by 12 feet	100 to 200	1 lavatory per company.

SECTION III

SUPPLY FACILITIES

■ 195. PORTS.—*a. Supply debarkation.*—Wartime port facilities ordinarily are provided by expansion or adaptation of existing facilities. Experience shows that about 1.25 tons per day per linear foot of dock frontage can be unloaded. Assuming supply shipments at the rate of 40 pounds per man per day, 16,000 linear feet would be required for a force of



A TYPICAL PORT
THEATER OF OPERATIONS

FIGURE 116.—Schematic plan of a typical port layout

1,000,000 men. Several additional docks should be provided for unloading ammunition, each about 150 feet long, or sufficient to receive two lighters at one time. Lighters and barges also can be used for handling cargoes and unloading troops. Figure 116 is a schematic plan showing track layout of a typical port. The railroad facilities required are similar to those in a storage depot (fig. 117). When conditions permit, the wharves and the base storage depot should be located in the same area, allowing one set of receiving and departure yards, coal storage, and car-repair facilities for the entire installation. For a port alone, with no adjacent depot, approximately 70 miles of track are required for a dockage of 8,000 feet front. The entire wharf and storage space should be accessible to trucks. Initially, cargoes are unloaded using ship's tackle. Cargo-handling machines may be installed later if the amount of tonnage handled is large.

b. Troop debarkation.—In addition to the facilities shown in figure 116, a port for debarking and entraining troops should include a troop entraining yard and a camp nearby with quartermaster warehouse, messing, bathing, and hospital facilities. For debarking and entraining 10,000 troops per day, the total trackage will amount to about 35 miles, and the camp should provide for 20,000 men, with expansion possible to 40,000-man capacity.

■ 196. DEPOTS.—Depots are supply installations for the reception, storage, issue, and shipment of supplies. General depots serve two or more supply services and arm or service depots a single arm or service. The essential facilities in the two types of depots are the same.

a. General depots.—(1) Figure 117 shows a typical layout for a general storage depot. The warehouse area is laid out in sections. Each section has a ladder track on each side connected by house tracks about 1,700 feet long (forming the rungs of the ladder). Thus three 500-foot warehouses can be served by each house track. The house tracks are 150 feet apart, allowing space for open storage on the opposite side of the track from the buildings.

(2) Initially supply services should be assigned locations each with room for expansion and separated by distances of 1 to 5 miles for purposes of dispersion. Construction in all locations should proceed simultaneously. Storehouses should be distributed to permit storage of each type of commodity on its individual track and to permit a commodity being loaded on one track while being received on another. Existing roads

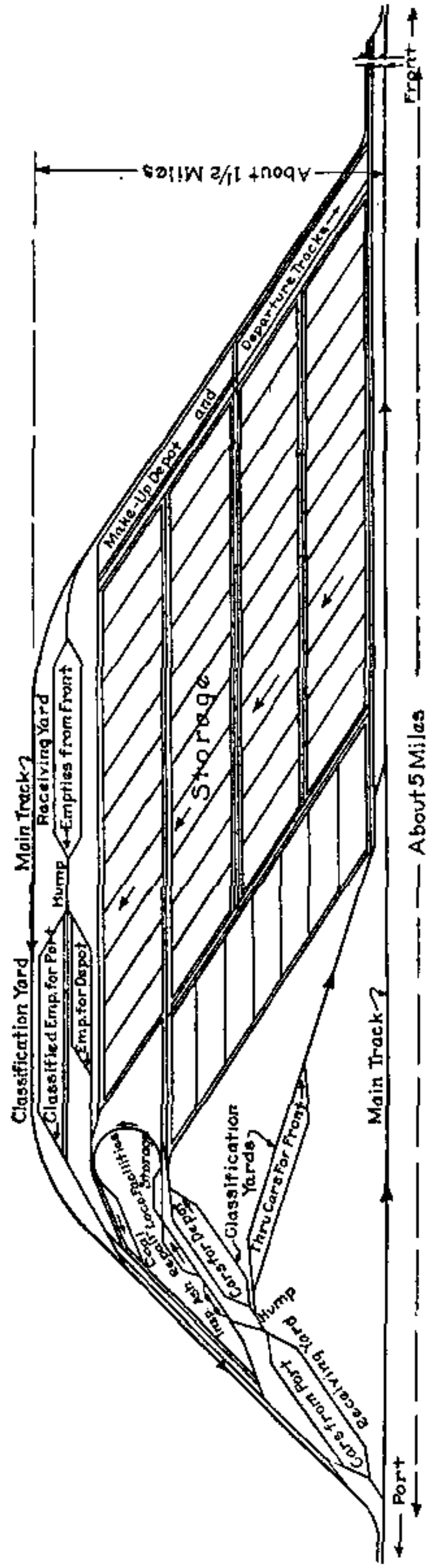


FIGURE 117.—Schematic plan of a typical storage depot layout.

should be blocked only when necessary. Warehouses near roads are needed by each supply service to permit truck shipments.

(3) Buildings are spaced sufficiently to prevent fire from spreading from one to another. Groups of warehouses are separated by open storage spaces. Hay and dynamite are stored on isolated sidings. No water pipe and fire hydrant system is provided because of prohibitive cost.

(4) Figure 118 shows a suitable type of wooden warehouse. It is 20 feet wide, and can be extended to any desired length. Sides are necessary only on buildings for storage of perishable supplies. In place of windows, the sides may be carried to within 12 or 18 inches of the roof, leaving a continuous opening protected by the eaves. Doors are not essential; canvas curtains are sufficient. In general, floors are not necessary. To preserve perishable supplies from water, dunnage consisting of wood poles overlaid with rough plank may be used. Floors at car level are not constructed, because of scarcity of time, labor, and materials.

(5) Cold-storage plants for meat preservation may be required. Unless type plans are provided, their design should be based on civil practice, modified to meet military exigencies.

(6) Bakeries and coffee-roasting plants may be necessary. The former require an ample water supply nearby.

(7) A special warehouse is desirable for use in making up less than carload shipments from the various departments. The warehouse should be near the departure yard.

(8) Camps for depot operating troops should be located on existing roads, and so distributed that personnel belonging to each supply service can easily walk to work.

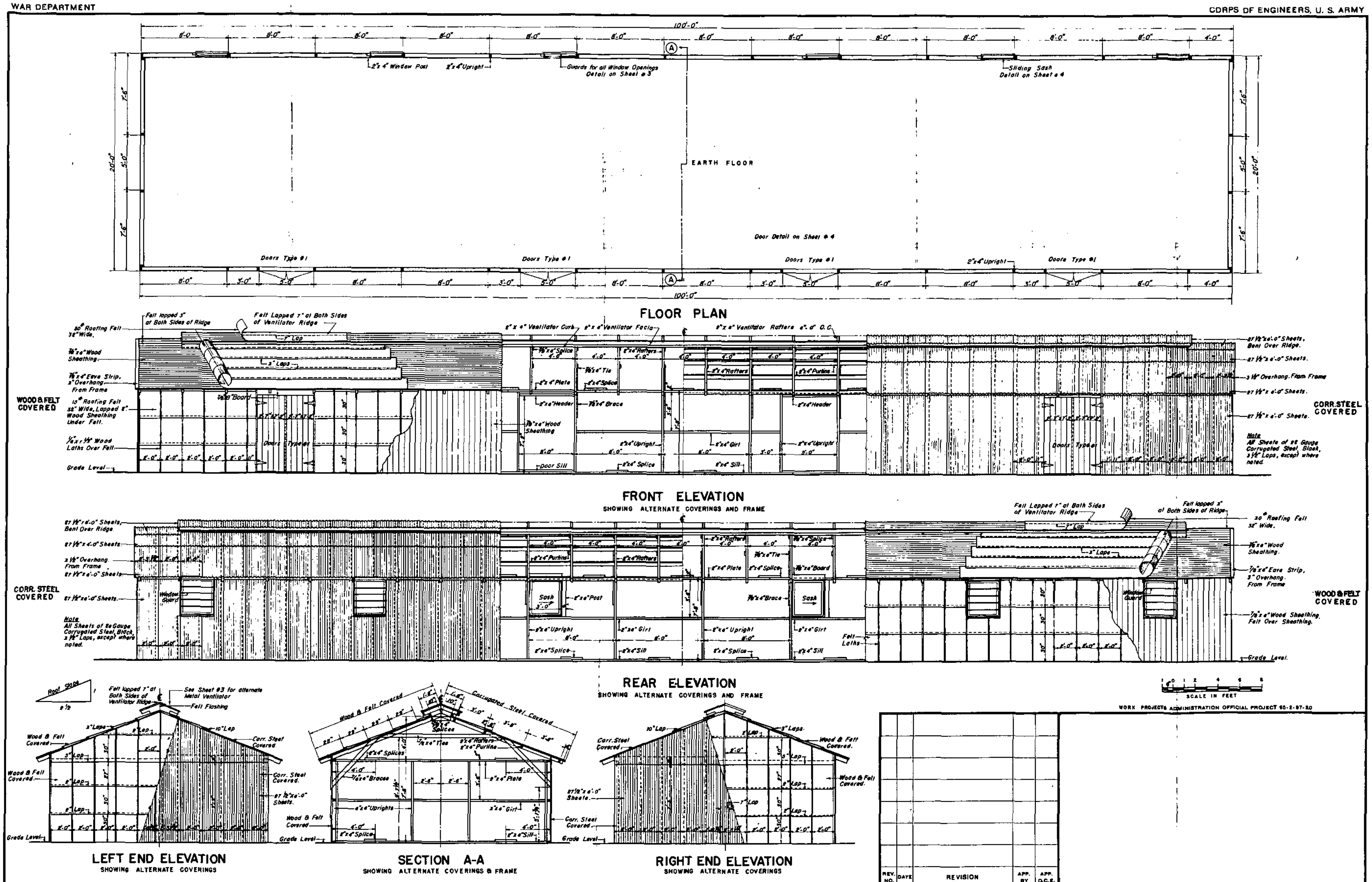
(9) A warehouse should be provided for local issues to the camp for the depot operating troops. It is essential to separate the supply functions of the camp and the depot.

(10) Necessary office space for each supply service should be provided in standard buildings adjacent to the respective storage areas.

(11) *Water supply.*—In addition to water for personnel, there must be water for locomotives and possibly ice plants

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



(Face p. 322)

FIGURE 118.—Warehouse.

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and bakeries. A large depot may use about 500,000 gallons per day.

(12) *Electricity.*—Experience has shown that in the intermediate and base depots very little night work is necessary, and it is unnecessary to install electric lights in the warehouses. Portable illuminating sets may be used in emergencies.

(13) *Railway facilities.*—A general storage depot requires so much railway operation in connection with the depot that engine terminal facilities near the depot are essential. They are shown in figure 117. In the storage area, the cars are pushed into the storage track from the ladder on one side and taken out at the other, thus always maintaining a flow in one direction.

b. Ammunition depots.—Ammunition, other than small arms, is stored in Ordnance Department depots. To localize the effect of accidental explosions, as well as to minimize the damage from aerial bombing, warehouses and open storage areas are separated from each other and from other facilities by 200 to 800 feet. Limited railway yard facilities are needed for making up ammunition trains. Administration, traffic, and living facilities common to all types of depots are also necessary.

c. Motor transport depots.—Quartermaster Corps depots include those for reserve pools of motor vehicles. Repair facilities and open storage parks are needed. Standard buildings, storage sheds, and warehouses are used for repair and for spare parts storage. Storage parks are graded and drained, but not surfaced. A camp for personnel is provided.

SECTION IV

AIR CORPS FACILITIES

■ 197. GENERAL.—The Air Corps may require special construction at airdromes, depots, and training centers. An airdrome is an establishment including a landing field and facilities for the maintenance, administration, supply, and repair of the unit. Air Corps depots are basically similar to general depots. A training center is an airdrome used primarily for the training of new personnel.

■ 198. AIRDROMES.—*a. Base airdromes.*—Base airdromes are generally similar to Army air fields constructed in the zone of the interior in time of peace, except that buildings are of a more temporary nature.

b. Advanced airdromes.—(1) An advanced airdrome requires a landing field, airplane parking areas, personnel shelters, limited repair shelters, ammunition dump, truck park, and gasoline storage areas. Roads to and within the airdrome are necessary. Some clearing and grading are usually necessary, but should be held to a minimum, as new work is difficult to conceal from air observation. Drainage may be provided by subsurface drainage pipes.

(2) An advanced landing field should be well drained and hard enough for all-weather use by the type of plane which will use it. Grass should not be over 15 inches high. Paved runways are not required except where especially heavy planes are expected to land. At such fields paved or stabilized runways must be installed in accordance with current practice. Usually a landing strip in the direction of the prevailing wind and another somewhat shorter strip in the direction of the usual storm winds will suffice. Wind directions can be determined from weather records. Generally a landing strip should be at least 3,000 feet long by 500 feet wide in order to permit planes to take off in formation. This length should be increased 250 feet for each 1,000 feet elevation above sea level. It is necessary also that a dead space be provided at the end of each landing strip so that a plane descending or ascending on an angle of 1 on 6 from the end of the field will clear any obstacle by 100 feet. Landing strips should have no grades steeper than 2½ percent and no change in grade of more than ½ percent in any 100-foot interval. Some form of boundary lighting around the field should be provided.

(3) Airplanes should be parked in dispersed areas under available cover. Hangars are generally undesirable because of concealment difficulties. Where suitable cover is lacking, airplanes should be spread out over the field, camouflaged as much as practicable.

(4) Personnel is sheltered in existing buildings within a 5-mile radius of the airdrome or in tents.

(5) An operations office, located for good observation of the landing field, is needed. A machine shop is also necessary. These facilities should be in small, concealed buildings.

(6) The ammunition dump, gasoline-storage area, and truck park should be located where damage from explosion will be minimized.

(7) Repairs can normally be made in the open or under a canvas shelter. Repair hangars are not furnished ordinarily.

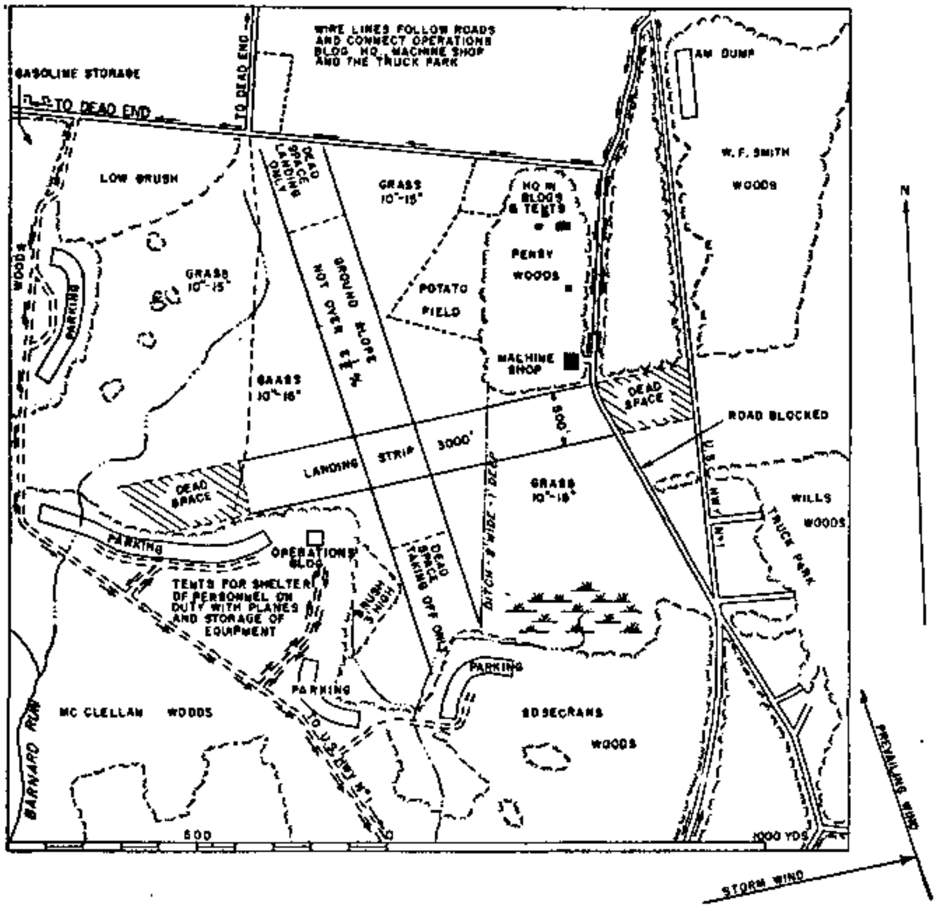


FIGURE 119.—Typical advanced airdrome.

(8) Figure 119 shows a typical advanced airdrome. It is important that this plan be varied in different installations for concealment purposes. Nothing in the nature of a "type layout" should be used.

■ 199. DEPOTS.—Air Corps depots are often combined with salvage and repair plants. These installations require shop buildings, hangars, and a landing field besides the usual depot facilities. A good type of shop building can be constructed by erecting several steel hangars side by side. A concrete floor is desirable. An apron across one end is useful for stripping damaged planes, uncrating parts, and for open storage. Closed storage for engines, wings, and fuselages should be provided adjacent to the apron. A steel hangar separate from the shop should be used for painting planes to lessen the fire hazard. A repair and salvage depot can also be used as an assembly plant if new planes are received unassembled.

■ 200. HANGARS.—Hangars are used for plane repair and storage in rear areas, and under special circumstances in advanced areas. Type plans for hangars will be available in the theater of operations. Wider buildings may be constructed if necessary by modifying type plans. A hangar should be about 10 feet wider than the wingspread of the largest plane it will accommodate, and must have adequate vertical clearance. Hangars are wood or steel framed and may be sheathed with canvas, wood, or corrugated steel. Steel hangars require about 12 man-hours to construct per 100 square feet of floor area.

SECTION V

SUMMARY

■ 201. SUMMARY.—*a.* Construction in war must be governed by the basic fundamentals of simplicity, economy of materials, use of type plans, and provision for future expansion.

b. A construction force should be built up gradually from a small nucleus at a rate proportional to construction progress and receipt of materials.

c. The standard building, 20 by 100 feet, is designed for general use in the theater of operations.

d. Semipermanent camps require facilities for shelter, sanitation, messing, administration, and storage.

e. Hospitals require facilities for wards, operating, messing, sanitation, administration, and quarters for medical personnel.

f. Ports require dockage, railroad yards, storage areas, administration buildings, and camps for transient and operating troops.

g. Depots require railroad facilities, open and covered storage areas, administration buildings, camps for operating troops, and miscellaneous facilities relating to supply.

h. The Air Corps requires special construction at airdromes, depots, and training centers.

CHAPTER 7

WATER SUPPLY

Section I

GENERAL

■ 202. Water Supply in Theater of Operations.—*a. Methods.*—Water is procured locally by using organizations wherever practicable. However, when local supplies are limited or unsatisfactory, engineer personnel install and operate such water supply facilities as are necessary.

b. Responsibility.—(1) The Corps of Engineers is responsible for the supply of water for all purposes to all major units of the army in the field down to and including the division, and to smaller units if practicable.

(2) The responsibility of the Medical Department in connection with water supply is covered in AR 40–205, which reads in part as follows:

> The Medical Department is charged with the duty of investigating the sanitary condition of the Army and making recommendations in relation thereto, of advising with reference to * * * the quality of water supply and purification * * * and the execution of all measures for conferring immunity from disease on military personnel.

(3) In general, responsibility for the quality of water supplied to troops in the theater of operations to include delivery to the point where it is distributed to using organizations rests with the engineers, assisted as may be necessary for laboratory examination by attached Medical Department personnel. The handling of water in organization water containers, in sterilizing bags, and in the canteen of the individual soldier

is a responsibility of the organization commander acting with the advice and assistance of attached medical personnel.

c. *Water discipline.*—The purpose of water discipline is to protect the health of troops by restricting them to the use of safe water, to conserve water by eliminating waste, and to safeguard the quality of water by enforcing proper sanitation. Engineers, in cooperation with the Medical Department, should recommend to their tactical commanders the measures to be taken for enforcement of water discipline.

d. *Duties of engineers.*—Engineers have the following general duties in connection with water supply:

(1) Reconnaissance and collection of data.

(2) Development of sources.

(3) Purification.

(4) Construction and operation of establishments.

(5) Transportation to distributing points.

For a discussion of engineer water supply operations in higher units see FM 5-5.

e. *Activities of unit engineers.*—In addition to the general water supply duties, unit engineers are responsible for the following specific activities within their areas:

(1) Recommendations as to methods of supply, quantity of water to be supplied, and conservation of water.

(2) Collection and transmission to higher echelons of data pertaining to water.

(3) Enforcement of water discipline at water supply points.

(4) Regulation of traffic at water supply points.

(5) Posting of signs to indicate safe and unsafe water.

(6) Preparation of maps and sketches to show locations of water supply points.

(7) Maintenance of records of water supply establishments in the area.

(8) Arrangements with higher engineer echelons for the delivery of water by truck, railway, or pipe line when local supplies are inadequate.

f. *Functions of engineer units.*—(1) General engineer troops normally execute all engineer water supply tasks, except those involving the transportation of water by truck or railway and the operation of purification trucks.

(2) Water supply battalions are responsible for the transportation of water by trucks into areas where local supply is inadequate and for the operation of purification trucks. For detailed discussion of the water supply battalion, see FM 5–5.

(3) Railway operating battalions may be required to transport water by rail, but will be charged only with the movement, and not with the filling or emptying, of cars.

g. General considerations.—(1) Initial water supply installations in the theater of operations will generally be crude and will be designed to meet minimum requirements only. Local water sources and existing facilities will be used to the fullest extent possible.

(2) Wide dispersion of water supply establishments is effected whenever possible in order to limit and minimize hostile attack from the air.

(3) Because of the difficulty of concealing water supply establishments from enemy observation, extensive camouflage measures must be taken. Storage tanks are conspicuous by their shape and, unless covered, they may be identified readily from the air by the reflection of light from the water surface. Railway tank cars and trucks are also very conspicuous unless adequate concealment is available.

(4) Water supply work in forward areas is taken over by engineers of rear echelons whenever time and existing conditions permit.

■ 203. WATER SUPPLY POINTS.—*a. Definitions.*—(1) Water supply points are establishments for the procurement, reception, storage, or delivery of water in the field. Facilities may be provided for one or more of the following functions: filling large containers, filling canteens, watering animals, bathing, or washing clothes. Water supply points are classified as watering points and water distributing points.

(2) A watering point is a place organized and operated by a consuming organization, at which it obtains water directly from the source with its own personnel and equipment. This method of supply is used whenever the quality of available water permits.

(3) A water distributing point is an establishment organized and operated by the engineers at which one or more consuming organizations obtain water. This method of supply is used whenever the available supply is limited or is badly contaminated, or whenever congestion would result from several organizations using the same point. It may be located at a natural source or water may be brought up by tank truck. railway tank cars, or pipe line.

b. General.—(1) The number of water supply points established depends upon the location and capacity of available sources and upon the number of troops to be supplied. Distributing points are generally installed at the rate of two or three per division or unit of similar size. As a rule, several small water supply points will serve better than a few large ones.

(2) The order of taking water from a stream, from upstream downward, is as follows:

(*a*) Drinking water for personnel.

(*b*) Watering animals.

(*c*) Bathing.

(*d*) Washing clothes.

(3) Water for human consumption is chlorinated as a matter of protection. This will be accomplished by consuming organizations, using the issue calcium hypochlorite tubes if the water has not previously been treated or if it may have become contaminated since treatment. In some cases it may be desirable for the engineers to provide purification, including chlorine treatment at the distributing point or prior to receipt thereat, utilizing existing plants, small improvised fixed plants, or the purification truck.

c. Control of traffic.—In order to prevent congestion, a carefully developed plan of traffic control must be enforced at water supply points. It is essential that this plan be coordinated with the general scheme for traffic control within the area. In keeping with this plan, signs must be posted to guide vehicles, personnel, or animals to water supply points and to direct them while passing through. Schedules allotting hours to using units are prepared in order to smooth out traffic flow, and guards are posted to enforce the traffic plan.

d. Location and layout of water-distributing points.—(1) The following factors should be considered in locating a water-distributing point:

(*a*) Proximity to kitchens and troops to be supplied.

(*b*) Accessibility to water source.

(*c*) Safety from enemy light artillery.

(*d*) Concealment from enemy air and ground observation.

(*e*) Parking space for waiting vehicles.

(*f*) Situation with regard to general scheme for traffic control.

(*g*) Existence of a natural elevation suitable for installation of storage tanks.

(*h*) Hardness of ground and natural drainage.

(*i*) Type of containers to be filled.

(2) Figure 120 shows a typical layout for a water-distributing point.

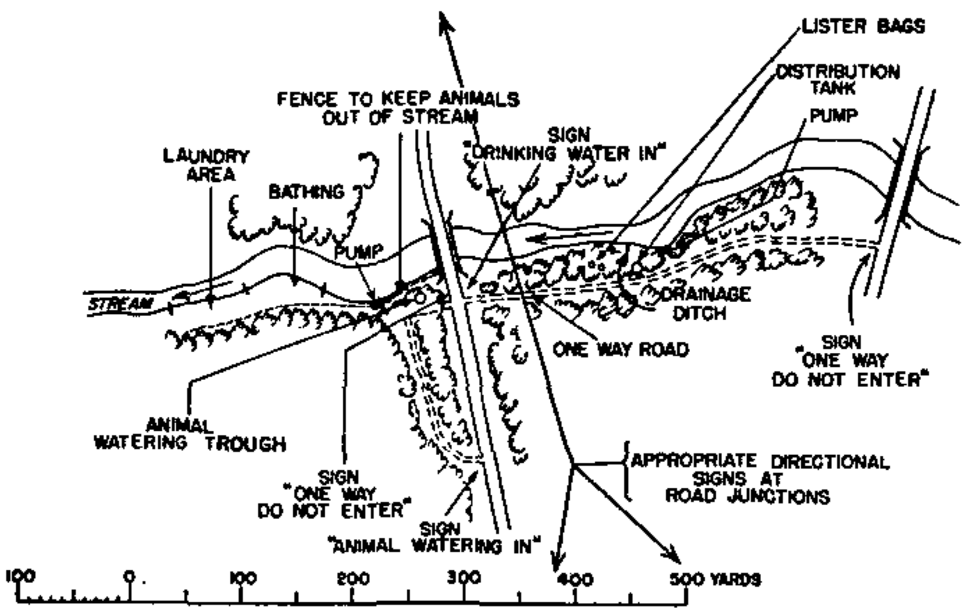


FIGURE 120.—Typical water-distributing point.

(3) The following tables present data relative to the installation and operation of water-distributing points.

TABLE LV.—*Man-hours for installing a water-distributing point*

Task	Man-hours required	Size of party	Remarks
Erect timber trestle platform for 3,000-gallon canvas tank.	16	1 or 2 squads	Materials at the site using power tools.
Erect 3,000-gallon tank	2	1 squad	After platform is constructed.
Set up pump and hose	1	½ squad	
Install 260-gallon animal-watering tank and hand pump.	1	½ squad	

TABLE LVI.—*Type organization for operating a water-distributing point*

Task	Size of party	Remarks
Filling milk cans	1 squad	2 shifts of ½ squad each.
Operating power pump	2 men	2 shifts of 1 man each.
Traffic police	As required	3 shifts.
Air guards	As required	3 shifts.

(4) Organizations are supplied with 10-gallon milk cans for carrying water. A 1½-ton truck will carry 30 cans. At the distributing point the cans may either be filled on the truck or replaced from a reserve of filled cans.

e. Animal watering.—Animal watering basins should be used in preference to direct watering from a stream unless the approaches are wide and open and the water downstream is not to be used by personnel. A fence should be improvised along the stream bank so as to make watering from the basin easier than from the stream. With the standard circular 260-gallon basin, animals are led to the basin in groups of 10 and remain at the basin until all are watered. Each group of animals requires about 5 minutes at the tank. The hose supplying a watering tank should be buried to prevent animals from cutting it. Gravel should be spread and ditches dug to provide drainage.

f. Storage tanks.—Storage tanks are usually elevated, either by taking advantage of an existing natural elevation or by the construction of a trestle platform. One disadvantage of an elevated tank, however, is the difficulty of camouflage. For this reason it may sometimes be desirable to pump direct from the stream or to install a tank in a concealed position on the ground and depend upon pumping for the necessary distribution of water. A type design of timber trestle platform for the 3,000-gallon canvas storage tank is shown in figure 121.

Demountable trestle platforms for water storage tanks may be improvised from pipe or angle iron. Foundation conditions must be given special consideration when installing a trestle platform, as the surplus water continuously spilled around a water distributing point may greatly reduce the bearing power of the soil supporting the platform. Footings may be required. Often it is advisable to install shims, so that inequality of settlement between supports may be taken up. A tank can be improvised by digging a hole and lining it with canvas.

g. Pumps.—(1) Portable, gasoline-driven, rotary, and centrifugal pumps furnish the normal means for raising water at water supply points. Centrifugal pumps are limited to a maximum suction lift of 25 feet. However, a 10- or 12-foot suction lift (or less when possible) results in more satisfactory operation. The usual types of portable pumps have the following characteristics:

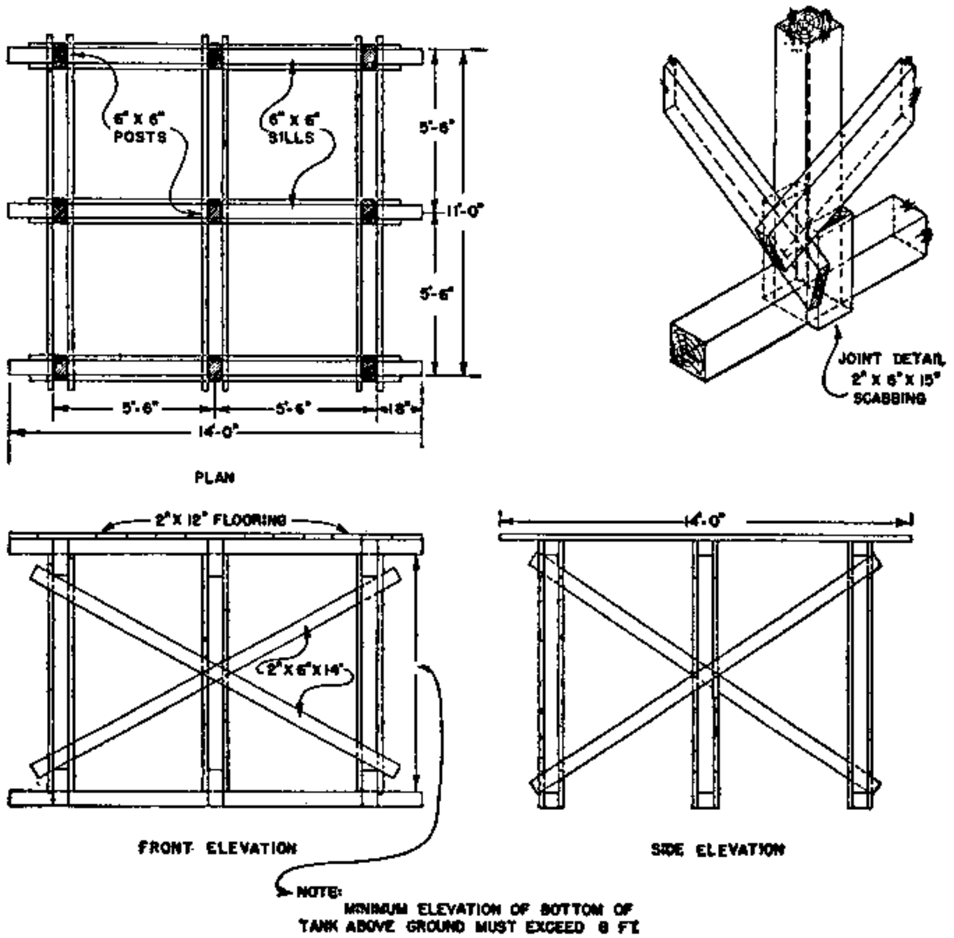
	Rotary	Centrifugal
Capacity (gallons per minute)	65	50
Total head of water (feet)	100	50
Size of connections (inches in diameter)	2	2
Speed (revolutions per minute)		1,900
Power (horsepower)	8	2

(2) Hand pumps are provided for auxiliary and emergency use. The following characteristics of the standard issue hand pump may be considered typical:

Capacity against a 5-foot head, men working in relays: 20 gallons per minute.

Size of connections: 2-inch.

(3) The air lift pump is adapted to supplying large amounts of water from great depths. Compressed air is forced down an air pipe and delivered near the bottom of a discharge pipe,



BILL OF MATERIAL

NO. PIECES	SIZE	LENGTH	ITEM
6	6" x 6"	14'	CAPS AND SILLS
9	6" x 6"	8'	POSTS
12	2" x 6"	14'	BRACES
16	2" x 12"	14'	FLOORING
36	2" x 6"	15"	SCABS
45 LBS.	40 D		NAILS

FIGURE 121.—Timber trestle platform for the 3,000-gallon canvas storage tank.

where it expands and rises, bringing water with it. The length of the submerged portion of the air pipe should be from 30 to 70 percent of the distance from the bottom of the air pipe to the point of discharge. It is preferable to have 70 percent submergence of the eduction pipe. The pressure used ranges from 20 to 100 pounds per square inch and is usually one-fifth to one-fourth pound per foot of lift.

(4) A canvas-belt elevator can be quickly installed in an open well. An endless 8-inch canvas belt, running over a 15-inch belt drum, is used with the bottom loop immersed in the water 6 inches from the bottom of the well when at rest. Water is taken off by a scraper at the top, or at high speeds by centrifugal force. Elevators can be constructed to deliver 1,000 to 2,000 gallons per hour from depths of 40 to 200 feet. Their chief disadvantage is the lack of durability in the belts. Slip can be avoided by tacking a 4-inch strip of canvas around the middle of the pulley, and for the shallower wells using two or more belts superimposed. A 3- to 5-horsepower gasoline engine is a suitable power unit for driving the belt.

(5) The purification truck, when operated as a simple pumping unit, has a rated capacity of 100 gallons per minute against a 90-foot head (including a 20-foot suction lift).

(6) The pump utilized on the portable purification unit is rated at 50 gallons per minute against a total head of 50 feet (including a 15-foot suction lift).

Section II

RECONNAISSANCE

■ 204. General.—*a. Purpose.*—Water reconnaissances are conducted to—

(1) Locate potential water sources.

(2) Determine the quality of water at such sources.

(3) Determine the quantity of water which may be available.

b. Personnel.—Medical personnel may be of value on a reconnaissance to assist in determining the purity of water. Officers of the water supply battalions, because of their special training, are particularly suited for water reconnaissance missions. However, general engineer troops are responsible for such reconnaissances within their respective areas.

■ 205. SOURCES OF WATER INFORMATION.—Information of the water resources of an area may be obtained from federal, county, or city reports, topographical and geological maps, and airplane photographs; by interrogation of the local officials and residents or prisoners; and by personal reconnaissance of the ground. In arid countries the assistance of a qualified geologist should be sought.

■ 206. EQUIPMENT OF RECONNAISSANCE PARTY.—In addition to the equipment customarily carried by parties engaged in general reconnaissance, a water supply party may find use for the following:

Several sterile glass bottles holding from 2 quarts to a gallon each, complete with a well-fitting stopper and a label for each bottle.
Several larger containers of known size for use in making volumetric measurements.
Stop watch.
Thermometer.
Camera.
Pair of hip boots.
Calibrated sounding rod.
Small alcohol torch.
Ball of heavy cord.
Pocket knife.
50-foot steel tape.
Small hatchet.
Crosscut saw.
Several tent stakes.
Assorted nails.
Flashlight.

■ 207. LOCATING POTENTIAL SOURCES.—Clues to the presence of water should be noted during a reconnaissance. Some of these are as follows:

a. Streams in open country are usually bordered by trees.

b. Spots where the grass is greener in one place than in another or the vegetation more abundant are likely to be near ground water.

c. Vapor often rises in the early morning or evening from places where springs or ground waters may be found.

d. Springs are often found at the junction of valleys or at the base of an overhanging cliff.

e. Areas suitable for shallow wells will usually be found in valleys.

■ 208. QUALITY OF WATER.—*a. Potability.*—This is determined by the general color, taste, and odor of the water. Bad-tasting water may be entirely harmless from a sanitary standpoint, yet undrinkable by personnel. While it is not always possible to obtain perfection in appearance and taste, it should nevertheless be sought.

b. Pollution (bacterial contamination).—Pollution of water results from the introduction of disease-producing organisms, usually from human excreta. The nature of the terrain, the extent and direction of surface drainage, the geology and resulting subsurface drainage, and the proximity of human habitation are factors affecting the possible degree of pollution. Typhoid, dysentery, and cholera are important waterborne diseases.

c. Chemical contamination.—This may occur through chemicals picked up from the soil, from commercial waste, or through chemicals introduced by the enemy. In the first two cases the contamination is likely to be harmless except as it may affect potability, but in the latter case appropriate measures, such as distillation, must be taken to restore purity.

d. Hardness.—Hardness results from the presence of calcium or magnesium salts in the water and makes it unsuitable for use in boilers and undesirable for washing purposes.

■ 209. QUANTITY OF WATER.—*a. Wells.*—The rate of flow for wells may be determined roughly by reducing the water level a measured distance by pumping, noting the time required for the surface to resume its original level, and computing the capacity in gallons between the two levels. When this is not possible, a pumping test may be run, using containers of known volume, or an effort may be made to obtain the desired information by local inquiry.

b. Springs.—These may be rated by noting the time required to fill a container of known capacity, or, in the case of a large spring, by measuring the flow of the outlet stream.

c. *Streams.*—Stream flow may be determined by the formula $Q=av$, where Q is the quantity of water in cubic feet per second a the area of cross section of the stream in square feet, and v the mean velocity of the stream in feet per second. The cross section is determined by estimate or measurement. The mean velocity can be estimated by noting the velocity of a chip floating on the surface in the middle of the stream and multiplying by 0.75. Weirs can be used as an alternate method of measuring stream flow in ditches or in small, narrow, streams with steep banks. An improvised rectangular weir is shown in figure 122.

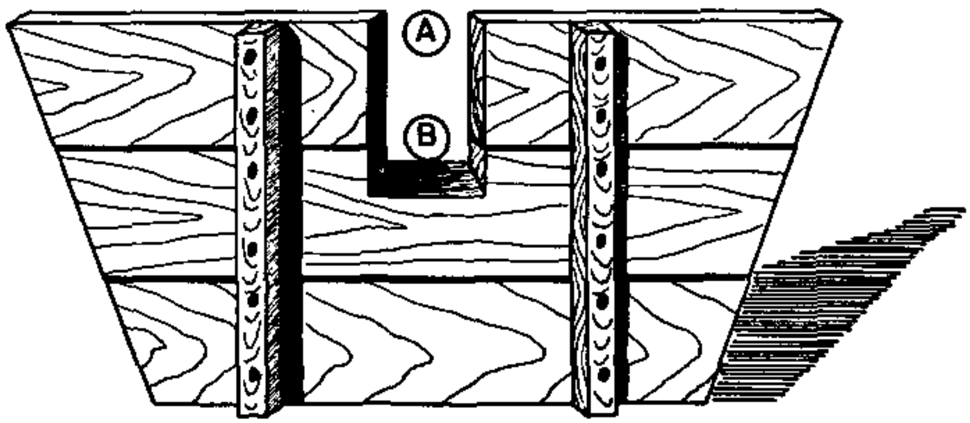


FIGURE 122.—An improvised weir.

The crest of the weir, that is, the bottom (*B*) of the opening (*AB*) is beveled so that it is not more than one-fourth inch thick. The high side of the bevel is placed upstream. Table LVII gives the flow of water through a rectangular weir with a 12-inch opening (measured horizontally). The depth in inches is measured from the crest of the weir to the surface of the water impounded by the weir.

TABLE LVII.—*Discharge over a rectangular weir 12 inches wide*

Depth in inches	Gallons per minute	Depth in inches	Gallons per minute	Depth in inches	Gallons per minute
1	36	4¾	375	8½	900
1¼	50	5	405	8¾	939
1½	66	5¼	436	9	978
1¾	84	5½	468	9¼	1,020
2	102	5¾	500	9½	1,062
2¼	122	6	533	9¾	1,104
2½	143	6¼	567	10	1,147
2¾	165	6½	601	10¼	1,190
3	188	6¾	636	10½	1,234
3¼	212	7	672	10¾	1,279
3½	237	7¼	708	11	1,323
3¾	263	7½	745	11¼	1,369
4	290	7¾	783	11½	1,414
4¼	317	8	821	11¾	1,461
4½	346	8¼	860	12	1,508

d. Artesian wells.—The flow of an artesian well may be determined by measuring the height of the jet from a vertical pipe and applying the data shown in table LVIII. The discharge for pipe sizes not given in the table may be obtained by applying the approximate rule that pipe discharge varies as the square of the diameter.

TABLE LVIII.—*Flow of artesian wells in gallons per minute*

Height of jet (inches)	Diameter of pipe (inches)			Height of jet (inches)	Diameter of pipe (inches)		
	1	2	3		1	2	3
½	3.96	15.6	35.6	15	22.0	87.8	198
1	5.60	22.4	50.4	20	25.4	102	228
2	7.99	32.0	71.9	30	30.9	123	278
4	11.3	45.3	102	60	43.8	175	394
6	13.9	55.5	125	108	58.9	236	531
8	16.0	64.0	144	144	68.0	272	612
10	17.9	71.6	161				

■ 210. REPORTS.—*a. Preliminary report.*—The most important information to be obtained and reported immediately is the location of satisfactory water supply sources and the rates of flow.

b. Complete report.—In making a complete report of a water reconnaissance the use of the following form is suggested:

WATER RECONNAISSANCE REPORT

Organization__________________
Place__________________
Date__________________

1. Location of water source: Map_________; map coordinates __________; local name__________.

2. Date and hour inspected__________________________________

3. Well, spring, stream, lake, pond (line out terms not applicable).

4. Rate of flow__________________ gallons per day.

5. Character of water: Clearness__________; taste__________; odor__________________.

4. Temperature of water__________°F.

7. Result of tests (if tests impossible at time of inspection, take sample of water as prescribed on back of sheet) (latest report of local Board of Health, if available).

____

____

8. Location of possible sources of pollution__________________________

____

9. Possibility of chemical contamination (chemical warfare agents, poisoning, etc.)____

____

10. Accessibility to railroad, highway, or trail_____________________

____

11. Well:

a. Type (dug, driven, drilled, or bored) (for definitions, see paragraph 213, FM 5–10).

b. Diameter: top __________ feet; bottom __________ feet.

c. Depth of well __________ feet.

d. Depth of water __________ feet.

e. Distance from surface of ground to water surface __________ feet.

f. Type, condition, and depth of casing or lining ______________

____

g. Present method of recovering water ______________________

h. Protection provided against entrance of surface water (coping, watertight basin, ditching, etc.) ______________________________

____

12. Spring:

a. Protection provided against entrance of surface water (coping, watertight basin, ditching, etc.)______________________________

____

b. Present method of delivering water ______________________

13. Stream or pond:

a. Sketch of cross section (show width, maximum depth, and height of banks above water surface) (reference to photograph, if one is made).

b. Surface velocity ---------- feet per second.

c. Nature of bed--

d. Nature of banks --

14. Existing installations:

a. Purification facilities (sedimentation tanks, chlorinating apparatus, filter, etc.) ------------------------------------

b. Pumps:

Type	Size (horsepower)	Speed (revolutions per minute)	Intake connection (size and type)	Discharge connection (size and type)	Capacity (gallons per day)

c. Engines:

Type	Size (horsepower)	Speed (revolutions per minute)

d. Electrical equipment------------------------------------

----

e. Storage facilities:

Type	Elevation (feet)	Capacity (gallons)

f. Pipe line layout (draw sketch showing arrangement, kind, lengths, and sizes of pipe, elevations, and heads of water):

g. Condition of existing installations--------------------------

----

----

15. Proposed development:

a. Description ____

____

____

b. Material available____

____

c. Material required____

____

d. Man-hours required____

____
(Signature)

____
(Grade and organization)

NOTE.—Back of sheet may be used for sketches or additional information.

The following instructions should be printed on the reverse side of the form:

INSTRUCTIONS FOR TAKING SAMPLES OF WATER

If sample is to be used for chemical examination only:

1. Use a clean glass bottle, holding from 2 quarts to a gallon, with a well-fitting stopper or a clean, unbroken cork.
2. Rinse out the bottle two or three times with the water to be sampled.
3. In sampling a well, support the bottle in a string or wire cradle, weighted at the bottom. Lower the bottle until the neck is 2 or 3 inches below the surface. It is advantageous to attach the stopper to a separate string, so the bottle can be opened below the surface of the water. In sampling a stream or pond, hold the bottle so the neck is well below the surface. Allow the bottle to fill.
4. Insert stopper or cork, stretch a clean cloth over it, and tie down the cloth below the flange of the neck.
5. Label the sample.

If the sample is to be used for bacteriological examination:

1. Use a sterilized bottle and stopper. Never use corks.
2. Avoid touching the neck of the bottle or the stopper with the fingers.
3. Before removing the stopper and after filling, the neck of the bottle should be held in a clean flame (alcohol torch) and heated to just over the boiling point of water (212° F.).

Precautions.—Never let the water entering the sample bottle flow over the hand. Before taking a sample from the spout of a pump or from a tap, allow water to waste for a time.

SECTION III

DEVELOPMENT OF SOURCES

■ 211. DEVELOPMENT OF SURFACE SOURCES.—*a. General.*—The methods of developing surface sources will depend on the amount of water required and may vary from an improvised water supply point installation to the construction of a large pipe-distribution system for the supply of a semipermanent camp or general hospital.

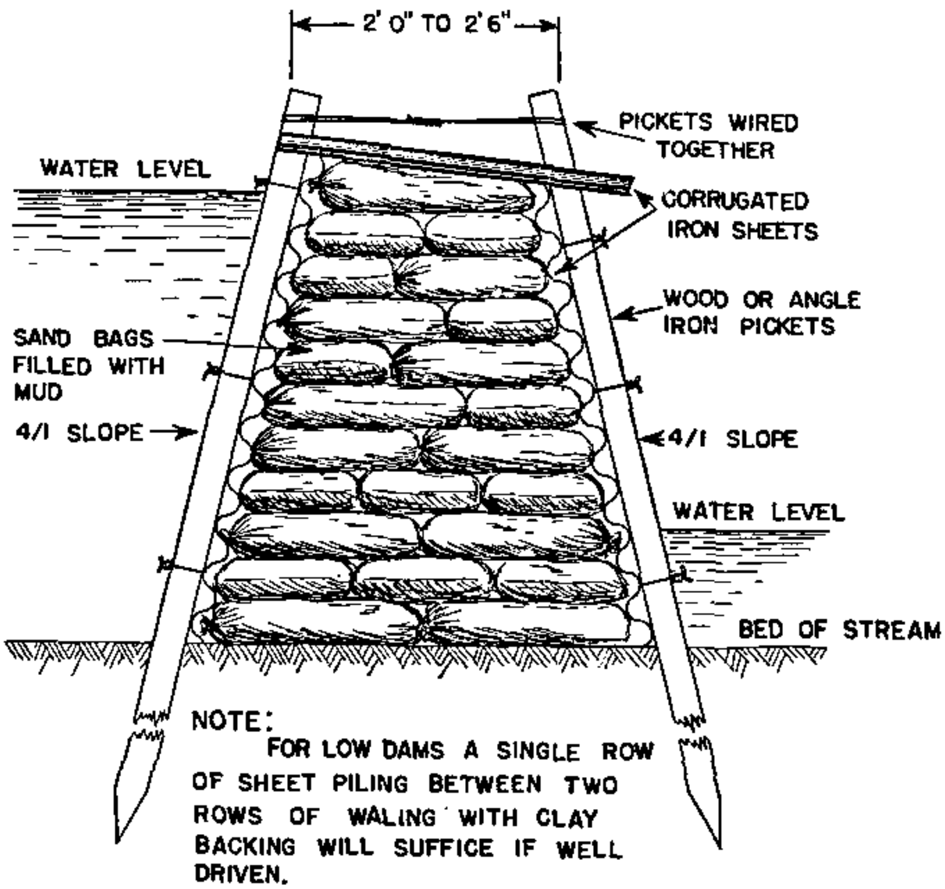


FIGURE 123.—Design for a small dam.

b. Dams.—Small dams are often constructed to provide bathing facilities for men or to provide storage to facilitate the suction of water by pumps. Such dams are ordinarily limited to not over 5 feet in height. A type design for a small dam is shown in figure 123.

c. Development of springs.—If a spring is to be developed as a water source, a substantial collecting basin is required. A watertight timber casing may be used, but will be objectionable if permitted to decay. Concrete or galvanized iron is preferable. Watertight walls should extend 1 or 2 feet above and below the surface to prevent the entrance of surface wash. Small springs may be developed by setting a length of large concrete, iron, or vitrified pipe in the ground vertically over the spring. A cover should always be provided to keep out dust, leaves, sticks, and small animals. Every care should be taken to guard against pollution, particularly such as might occur from dipping buckets or dippers into the spring, and the water should be taken by a pipe to the storage tank or point of delivery.

■ 212. INCREASING YIELD OF EXISTING WELLS.—*a*. An inadequate yield usually results from insufficient supply or from the slowness with which water is given up by the water-bearing strata. In clay and the denser varieties of till, water is given up slowly, and the amount of water in a well is more or less proportional to the area of surface exposed. Consequently, in such formations large wells are desirable. Large wells are also desirable in rocks in which water occurs in pores rather than in open passages. The depth of dug wells is important in providing increased storage. In some cases, where the water table has sunk, deepening alone will increase the yield sufficiently.

b. In deep wells the use of explosives shatters the surrounding rock and may result in opening other water-bearing crevices. Explosives are most effective in hard, brittle rocks, such as limestone, and least effective in soft, tough shales.

c. Packing with gravel is useful when the material surrounding the well is so fine as to clog the flow. Pebbles may sometimes be dropped into the well and forced out into the surrounding clay with a drill, until a pocket is produced permitting flow. The yield of wells in unconsolidated sands may often be increased by removing sand from around the strainer and substituting selected graded gravel. A coarse strainer is required, and the effective diameter of the well becomes that of the gravel pocket. The usual method of packing with gravel consists of pumping out sand through an inner casing and simultaneously feeding in gravel between an inner and outer casing. This means of increasing yield is most applicable to shallow wells in fine sands.

d. A gradual reduction in the flow of a deep well may be due to a drawing off of the general supply in the area, deterioration of the well from clogging of the screen, entrance of sand to working parts of a pump, or leakage of the well from corrosion of the casing.

■ 213. SELECTION OF TYPE OF NEW WELL.—*a. Types of wells.*—(1) A dug well consists of a vertical shaft 3 to 6 feet in diameter. Dug wells are usually constructed by hand labor. In soft ground they may require a lining.

(2) A driven well is constructed by driving into the water-bearing strata an iron pipe equipped with a strainer at its lower end. Either a closed-end (point) or open-end type of pipe may be used.

(3) Drilled wells, 1½ inches or more in diameter, are used in harder materials or where the depth is too great for driving. Sections through strata from which undesirable water might enter require an iron casing.

(4) Bored wells, 4 to 8 inches in diameter, are sunk with hand or power-driven augers. They can be put down through loose material and the harder clay formations, but cannot be constructed in soils containing large boulders or rock strata.

b. Depth to water.—The depth to water is of primary importance in determining the type of well. A dug well is usually only suitable for depths less than 30 feet. Driven wells are most suitable at depths of less than 150 feet, although at times they are carried to 300 or even 500 feet in suitable material. Bored wells are usually not carried more than 100 feet below the surface. Drilled wells may be carried to any depth, but in granite rock, if water is not found within 300 feet, it is better to try a new locality.

c. Character of water-bearing material.—Sand will furnish large supplies of water while chalk or clay, although possibly containing more water, will yield little or none. Quicksands contain large amounts of water but, owing to the ready flow of the fine sand through crevices, dug wells are impossible, and driven wells, unless equipped with special fine-mesh strainers, become clogged. Drilled or driven wells sunk by men familiar with the methods of handling quicksand and equipped with special strainers are usually the only types successful in such material.

d. Rock structure.—In loose materials, water accumulates most easily in stone-lined, uncemented dug wells, and somewhat less readily in tightly-lined dug wells with open bottoms. If the materials are so consolidated as to prevent their entering the well, suitable water may be obtained from an iron casing open at the bottom. In soft materials perforated casings or screens are necessary. In the harder rocks, casings are unnecessary except to prevent entrance from undesirable levels.

e. Storage.—The amount of storage in a well is important when the rate of flow is low. Storage capacity varies as the square of the diameter. For example, a 3-foot well will hold 36 times as much water as a 6-inch well. Dug wells are advantageous in any material where water enters more slowly than it can be lifted by the pumps. In rock, only small boreholes are practicable; but, if the flow is inadequate, such boreholes may be enlarged and deepened below the entrance point of water.

f. Usual types of well.—Since bored and drilled wells are useful only under special conditions, dug and driven wells are the types ordinarily used for military water supply, particularly in open warfare.

■ 214. DUG WELLS.—*a. Construction.*—(1) Dug wells are usually excavated with pick and shovel. A windlass and bucket must be provided for lifting out the excavated material. The size of the shaft depends on the amount of storage required, the type of lining, and the method of raising the water. Shafts using a windlass and bucket require a diameter of at least 4 feet. Where considerable storage is required in shallow wells, diameters of from 15 to 20 feet may be called for. It is usually desirable during excavation to install the permanent pump for use in removing water.

(2) Linings may be of brick, masonry, timber, concrete, or galvanized iron, depending on the diameter of the well, the

character of the soil, and the time and material available. For field use, timber is the most useful and shafts may be sunk as in mining operations. (See FM 5–15.) The top of the well should be secured from pollution by raising the lining above the ground level and covering the opening. For temporary use the top may be of timber with an impervious cover, but for semipermanent construction a concrete top should be provided. A manhole should be provided with the cover set on a curbing. A sleeve and gasket can be employed to protect the pump hole from waste water. The lining of the well should be watertight for at least 6 feet below the ground surface. (See fig. 124.)

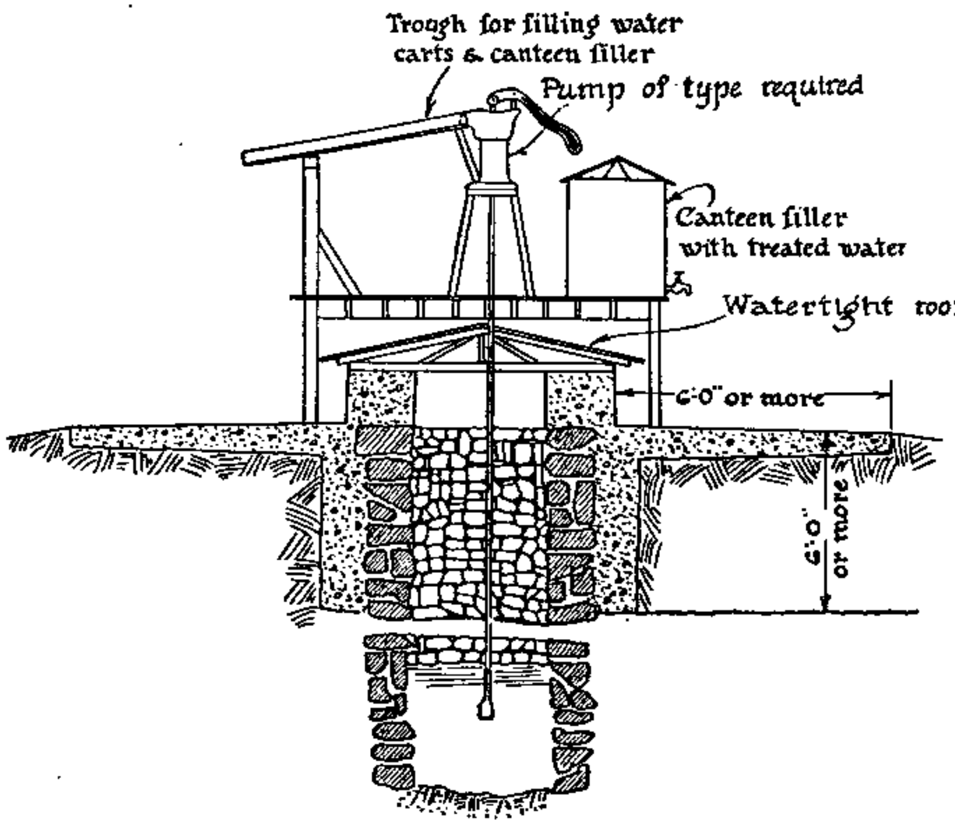


FIGURE 124.—Development of existing well.

b. Infiltration galleries.—An infiltration gallery is a modification of a dug well in which the ground water at moderate depths is intercepted by galleries extending across the line of flow. Such galleries are usually constructed in an open trench, and are arranged to lead the water to a pump well.

■ 215. DRIVEN WELLS.—*a. Location.*—When several wells are to be driven they are located so as to be in a line across the direction of underflow. In this way the maximum flow may be intercepted without interference between wells.

b. Construction.—(1) Driven wells are constructed by driving pipes into the ground with a maul or a driving machine, sometimes with the assistance of a jet or "wash drill." The pipes are usually ¼ to 3 inches in diameter (2-inch is the most common size), and the screens 2 to 4 feet long. New

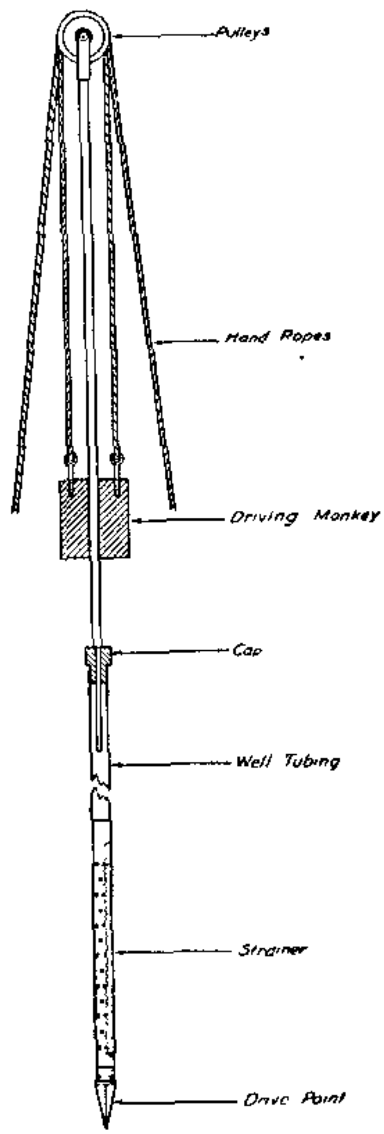


FIGURE 125.—Construction of driven well.

sections are screwed on as the pipe is driven. A portable and very simple arrangement for constructing driven wells is illustrated in figure 125. This arrangement is entirely suitable for moderate depths. A hollow cast iron monkey slides over a bar which is supported vertically by the tube to be driven. By means of two ropes passing over pulleys at the top of the bar, the drop weight may be alternately raised by hand and allowed to descend by gravity, striking a blow on an attached clamp or cap fitted to the upper length of well tubing.

(2) In a closed-end well, a drive point slightly larger than the pipe is used. A perforated section is provided above the point.

(3) Open-end wells are constructed by driving a plain pipe which may or may not have a heavy driving shoe attached. The material inside is removed by a sand pump or by a water jet forced down a small pipe inside the driven pipe. The pipe is perforated either before driving or by special tools after driving. A perforated strainer section about 2 feet long should always be used even if the bottom of the well is open.

(4) As a safeguard against pollution the casing should be thick enough to resist corrosion, should have tight joints, and should be carried above ground level. If located in a stream valley, casings should be carried above flood levels.

SECTION IV

PURIFICATION

■ 216. GENERAL.—*a*. (1) All water, whatever the source, should be considered dangerous until it is tested and designated as safe. Regardless of contamination, however, water should be disinfected before being used for drinking purposes.

(2) Water suspected of being contaminated with gas or chemicals must not be used until passed by the Medical Department.

b. Unsatisfactory quality of water may be due to—

(1) Pollution (bacterial contamination).

(2) Chemical contamination.

(3) Turbidity.

(4) Disagreeable color, taste, or odor.

(5) Hardness.

c. The purpose of water purification is to remove such of the above unsatisfactory conditions as may be necessary.

d. The common methods of water purification and their effect on the quality of water are tabulated in table LIX. In military practice any one or combination of these methods may be used.

TABLE LIX.—*Methods of water purification*

Method	Effect on quality
Sedimentation	Reduces turbidity and some forms of bacterial contamination; decreases some forms of color, if a coagulant is used.
Filtration	Removes turbidity and some forms of bacterial contamination and color.
Disinfection	Destroys most bacteria.
Softening	Removes or reduces hardness.
Activated carbon treatment.	Eliminates certain tastes and odors; reduces chemical contamination due to dissolved gases.
Aeration	Reduces odors and tastes due to dissolved gases; removes objectionable gases such as CO_2 and adds oxygen for oxidization of ferrous iron to assist in its precipitation.

■ 217. SEDIMENTATION.—*a*. Sedimentation will occur by the action of gravity alone in any quiet body of water. In a pond or reservoir water is often clarified in from 1 to 3 days. Should the suspended matter be composed of finely divided or colloidal clay, it may remain in suspension indefinitely. In water purification it is customary to use a coagulant, such as alum ($Al_2(SO_4)_3$), to form a gelatinous precipitate (called floc) which unites with the finely divided matter to form larger masses. This facilitates removal of suspended material either by sedimentation or filtration. For average surface waters, 0.14 to 28.5 pounds of coagulant to 100,000 gallons of water will produce satisfactory coagulation. When adding the coagulant, sufficient agitation to insure thorough mixing with the water is essential.

b. Alkalinity and acidity of waters are ordinarily measured in terms of the concentration of hydrogen ions. This is conveniently expressed by a scale known as pH values. The more alkaline a solution becomes, the higher is its pH value; and conversely, the more acid a solution becomes, the lower is its pH value. A pH value of 7.0 indicates a neutral solution such as pure water. A simple test set, utilizing a standard color disk and a special dye solution, is available for determining pH values in the field.

c. For any given natural water there is a narrow range of alkalinity or acidity (pH values) within which alum will react to produce satisfactory coagulation. This range of pH values varies with different waters, depending on the electrochemical characteristics of the dissolved and suspended matter carried by the natural water. The range is determined for each case by adding either acid or alkaline admixtures to the raw water until an admixture is determined which, in reaction with the alum, results in the most effective clarification of the water. In commercial practice sulphuric acid (H_2SO_4) is used to reduce alkalinity, while hydrated lime ($CA(OH)_2$) or soda ash (Na_2CO_3) are used to increase alkalinity. In the field, however, when the raw water is more alkaline than desirable, it is customary to add alum (which is an acid salt as well as a coagulant) to bring the pH value down to the range within which good coagulation will occur; and when the raw water is more acid than desirable, soda ash is added to increase the pH value of the water to the range within which alum will react to produce satisfactory coagulation.

d. When sedimentation is to be followed by filtration, complete clarification in the sedimentation basin is unnecessary, and better results are obtained when a small amount of the floc is carried to the filters. In the event that the water is not to be filtered, the water should be allowed to settle until clear. If this requires longer than 4 to 6 hours, clay or similar material should be fed with the coagulant to form nuclei on which the floc will form.

e. When water is to be distributed by metal pipe or retained for long periods in metal containers it is desirable that a chemical balance be developed in the water such that a small amount of calcium carbonate ($CaCO_3$) is deposited as a protection against corrosion. This balance is sometimes obtained during sedimentation and filtration without any other treatment, but usually it will be necessary to add soda ash before the water is distributed. When there is a deficiency of calcium it may also be necessary to supply calcium by adding hydrated lime.

■ 218. FILTRATION.—*a*. Sand filters are of the following types:

(1) Slow.

(2) Rapid.

(*a*) Gravity.

(*b*) Pressure.

b. *Slow sand filters* are designed to filter water which has not been subjected to any treatment with a coagulant. The construction of this type of filter is impracticable in the field on account of the size of plant and the time required, but such filters already in use may be taken over. Their capacity ranges from 2 million to 6 million gallons per acre per day.

c. *Rapid sand filters* make use of coagulants to assist a bed of carefully graded filtering material in removing suspended material from the water. Such filters may be improvised in the field for the supply of a semipermanent camp or other fixed establishment.

d. A *pressure filter* is a rapid sand filter to which water is applied under pressure. This method of purification is used in the purification truck.

e. In emergencies small quantities of water may be clarified by filtering through a blanket.

■ 219. DISINFECTION.—*a*. *Disinfection before distribution*.—(1) Water is usually disinfected by the application of some form of chlorine. In military practice a residual chlorine content of 1.0 part per million (by weight) is used to counteract pollution which may occur between the time of treatment and final use. This may require the addition of 2.0 or more parts per million of chlorine (about 17 pounds of liquid chlorine per 1,000,000 gallons) initially, since part of the added chlorine is dissipated in reaction with organic matter contained in the water.

(2) Sodium and calcium hypochlorite compounds are the most common chlorinating agents used in the field. These

chemicals contain about 60 percent chlorine. Hypochlorite is usually first dissolved in a small container of water, the solution then being added to the water to be treated in whatever proportion is necessary to produce a residual chlorine content of 1.0 part per million. Thorough mixing of the solution in the water to be treated is essential.

(3) Liquid chlorine may be applied to water by means of a chlorinator. In the solution type chlorinator a quantity of chlorine gas is dissolved in water under pressure. Then this solution is fed from the chlorinator into the water to be purified. Dry feed chlorinators, such as are used on the purification truck, feed the dry chlorine gas direct to the water through diffusers. They have the advantage that water under pressure is not required for their operation.

(4) An improved method of water treatment, known as the ammonia-chlorine (chloramine) treatment, permits a high and sustained residual chlorine content without the development of chlorous taste. The ammonia is usually applied as an anhydrous gas, but aqua ammonia, ammonia alum, or a solution of ammonium sulfate may be used. As a general rule the ratio of ammonia to chlorine averages about one to three, but where taste is not objectionable and disinfection only is sought, the ratio is adjusted to provide the maximum persistence of residual chlorine. The purification truck and the portable purification unit utilize a modification of this treatment, and obtain some of its advantages by the use of a coagulant.

(5) When water has been overchlorinated, sodium thiosulfate (sodium hyposulfite) or activated carbon (see par. 221) can be used to remove the excess of chlorine. This is needed only in cases where the taste of chlorine is so objectionable to troops as to cause them to drink from unpurified sources. Dechlorination is always inadvisable until the water has passed all stages where contamination is possible. There is no reason to believe that any amounts of free chlorine obtained by methods used in the purification of water are in the slightest degree harmful. It is desirable, however, to keep the free chlorine down to 2.0 parts per million or less.

Where tests are possible it can easily be kept to 1.0 part per million.

b. Disinfection by using organization.—(1) Individual organizations may disinfect their own water by means of the standard capsules of hypochlorite issued by the Quartermaster Corps. Ordinarily one capsule, dissolved first in a canteen cup of water, is added to the water contained in a sterilizing bag (Lyster bag). The water is then thoroughly mixed and the faucets of the bag flushed out. When gross pollution is suspected, two or more capsules per bag should be used. The water will be ready for use 30 minutes after mixing.

(2) Tincture of iodine may be used to disinfect water in an emergency. Two and one-half teaspoonfuls of standard 7 percent tincture of iodine is sufficient for one Lyster bag. Two drops of iodine are used to the quart of water in a canteen. The water will be ready for use 30 minutes after mixing.

(3) Boiling for 10 minutes may be used for sterilizing small quantities of water. Aeration, obtained by pouring from one container to another and back again, will improve the taste of water that has been boiled.

■ 220. SOFTENING.—*a.* Hardness in water is mainly due to the bicarbonates and sulfates of calcium and magnesium. Any hardness whatsoever is undesirable when water is to be used in boilers or laundries. Water containing hardness results in excessive soap consumption. Two hundred and fifty parts per million or more may not affect the suitability of water for drinking purposes.

b. The removal cf hardness due to bicarbonates can be effected by prolonged boiling. Softening of water containing other hardness-producing chemicals can be accomplished by precipitation. To remove the carbonates, hydrated lime ($Ca(OH)_2$) is added, precipitating calcium carbonate or magnesium hydroxide. To remove the sulfates, sodium carbonate (Na_2CO_3) is used (lime must be added in case of magnesium sulfate), producing sodium sulfate. When both bicarbonates and sulfates are present, crude caustic soda (Na OH) may be employed, in which case the final precipitate is calcium or magnesium carbonate. Hardness may also be removed by percolation of the water through special softening compounds known as zeolites.

■ 221. ACTIVATED CARBON.—Activated carbon (hydroarco or aqua nuchar) absorbs tastes and odors from water. Under the direction of water supply technicians it may be useful in purifying water which has been subjected to chemical contamination. Activated carbon is ordinarily applied in a mixing basin prior to sedimentation, either separately or together with the coagulant.

Carbon is often applied in the form of black alum or activated alum (alums to which activated carbon has been added during manufacture). Carbon also is sometimes used as a filtering material. The usual dosage of activated carbon ranges from 0.5 to 10.0 parts per million.

■ 222. SMALL PURIFICATION PLANTS.—Small purification plants can be improvised in the field as shown in figure 126. The coagulant solution is made up in tank *A* and added to the water as it is pumped into tank *B* from the stream, so as to be thoroughly mixed. The water should stand in tank *B* until clear. Clear water is drawn off into tank *C*, and sufficient hypochlorite solution is added to leave a residual chlorine content of 1.0 parts per million. The water is mixed

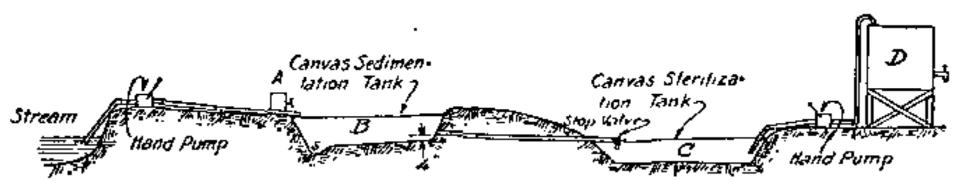


FIGURE 126.—Improvised purification plant.

thoroughly and after standing 30 minutes can be pumped to the storage tank *D*. The outlet pipe of tank *B* should be 4 inches above the bottom of the tank. There should be a depression at one end, *S*, to act as a sump for cleaning, and the tank should slope slightly in that direction. Sludge can be removed with a hand pump and a little water. The standard 3,000-gallon canvas tank can be used at *B*, *C*, and *D* and connections made with hose or pipe. If the water requirements are greater than 3,000 gallons in 12 hours, additional sedimentation tanks can be used.

■ 223. STANDARD PURIFICATION UNITS.—*a. Purification truck.*—(1) This truck (known as the mobile purification unit) carries a purification unit consisting essentially of a 4-cylinder, gasoline engine driven, self-priming, centrifugal pump; dry chlorine feeder; 42-inch pressure sand filter; alum and soda ash pots; and necessary piping, hose, and laboratory facilities. The unit (model M3) has the following technical characteristics:

Gross weight	8 tons.
Rated capacity of pump	100 gallons per minute against a total head of 90 feet (including 20-foot suction lift).
Approximate capacity of unit when filtering average water in the field.	70 gallons per minute.
Suction intake	2½ inches.
Discharge opening	2 inches.
Truck type	2½-ton, 6 x 6, standard quartermaster truck.

(2) The truck has laboratory facilities for making the following water tests:

Turbidity.
Alkalinity or acidity (pH value).
Chlorine content.

b. Portable purification unit.—(1) This unit consists of the following two sections:

(*a*) A 17-inch pressure sand filter and carrying handles and necessary piping.

(*b*) A pumping unit consisting of a one-cylinder gasoline engine driven, self-priming, centrifugal pump; calcium hypochlorite solution feeder; alum and soda ash pots; and necessary piping and tool boxes (all inclosed and mounted in a tubular steel frame). The unit (model 1940) has the following technical characteristics:

Gross weight	750 pounds.
Rated capacity of pump	50 gallons per minute against a total head of 50 feet (including 15-foot suction lift).
Approximate capacity of unit when filtering average water in the field.	10 gallons per minute.
Suction and discharge openings.	1½ inches.
Transportation	May be carried in any standard truck or trailer of ½-ton capacity or larger.

(2) Accompanying the portable unit are facilities and instructions for making the following water tests:

Alkalinity and acidity (pH value).

Chlorine content.

SECTION V

PIPE DISTRIBUTION

■ 224. DISTRIBUTION SYSTEMS.—*a*. There are three general systems of pipe distribution:

(1) Gravity distribution.

(2) Direct pumping.

(3) Indirect distribution.

b. In the gravity distribution system, mains are supplied by gravity alone, and no pumping is necessary.

c. Direct pumping is usually undesirable because of the danger of pump failure. Where it is used, a relief valve must be placed at the pumping station to provide for the possibility of valves being shut on the line. Duplicate sets of pumps should be provided, when possible, for use in case of breakdown.

d. In indirect distribution, water is first pumped into a storage tank from which distribution is effected by gravity.

e. A comparison of the three systems of distribution will usually indicate the adoption of gravity distribution where it can be utilized. Gravity and indirect distribution provide the following advantages over direct pumping:

(1) Greater reliability.

(2) A constant head.

(3) Storage to provide for unexpected variations in demand.

(4) Less trouble from water hammer.

■ 225. PIPE.—*a. Standard pipe.*—One-inch, 2-inch, and 4-inch pipes should be standard. The 4-inch size can easily supply 100,000 gallons a day and, by repumping, the water can be carried forward indefinitely. The 2-inch and 1-inch sizes are suitable for laterals to water points and for other distribution. Occasional need may arise for 6-inch and, in rare instances, for larger sizes in bringing water a considerable distance for a large camp. Universal joint and bell-and-spigot cast-iron pipe with lead-wool joints are used to some extent. Screw-joint pipe is found to be satisfactory, except that occasional trouble develops from crossed threads or from insufficient screwing when laid by unskilled men.

Special fittings vary greatly with conditions, but should include 45° and 90° elbows, tees, bushings, plugs, nipples, valves, couplings, and saddles.

b. Rate of laying pipe.—This depends on the accessibility of the pipe line location to supply trucks. However, with a platoon of trained men under good conditions, 4 miles of 4-inch pipe can be laid in a day, assuming that the trench is dug by other troops.

■ 226. PIPE FLOW COMPUTATIONS.—*a. Manning formula.*—The Manning formula for flow in open channels is:

$$v=\frac{1.486}{n}r^{2/3}s^{\frac{1}{2}}$$

When used for flow of water under pressure in pipes, it is made more conveniently applicable by substituting $\frac{d}{4}$ for r, as follows:

$$v=\frac{0.590}{n}d^{2/3}s^{\frac{1}{2}} \qquad (1)$$

Formulas 2 and 3 are convenient forms of the Manning formula for solving for discharge and head loss due to pipe friction.

$$Q=0.46\frac{d^{8/3}s^{\frac{1}{2}}}{n} \qquad (2)$$

$$H_l=2.87n^2\frac{lv^2}{d^{4/3}} \qquad (3)$$

In these formulas:

v=Mean velocity of water in feet per second.
d=Diameter of pipe in feet.
r=Mean hydraulic radius$=\frac{d}{4}$.
l=Length of pipe in feet.
H_l=Loss of head due to friction in feet in length l.
s=Mean slope of hydraulic gradient in distance $=\frac{H_l}{l}$.
Q=Discharge of pipe in cubic feet per second.
n=Manning coefficient of roughness, varying directly with the degree of roughness of the pipe. The value for cast iron pipe commonly falls between 0.013 and 0.015, with extreme values of 0.011 and 0.017.

b. Nomograph.—A nomograph based on the Manning formula is given in figure 127. A straight line on the nomograph, determined by given values of any two variables in the Manning formula, will pass through corresponding values for the other two variables.

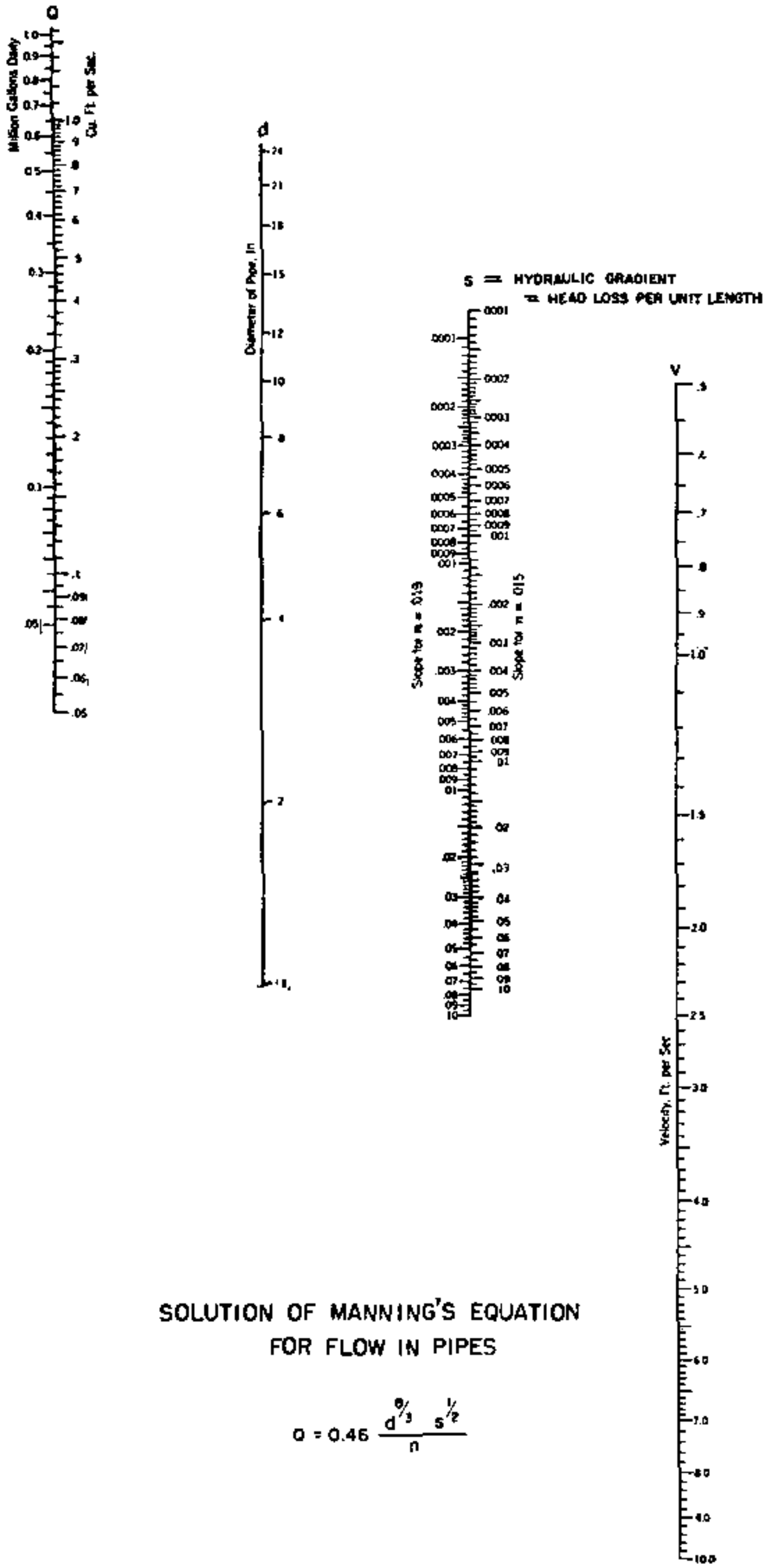


FIGURE 127.—Nomograph for solving the Manning formula.

TABLE LX.—*Equivalents and constants*

Value	Equivalent
Acceleration of gravity (g)	32.2 feet per second.
1 atmosphere	29.9 inches of mercury.
	33.9 feet of water.
	14.7 pounds per square inch.
1 cubic foot of water	62.4 pounds.
	7.48 gallons.
1 cubic foot per second	449 gallons per minute.
	646,000 gallons per day.
1 day	1,440 minutes.
	86,400 seconds.
1 foot of water	0.434 pounds per square inch.
1 United States gallon	231 cubic inches.
	0.134 cubic foot.
	8.35 pounds of water.
1 gallon per minute	1,440 gallons per day.
	0.00223 cubic foot per second.
1 horsepower	550 foot-pounds per second.
	0.746 kilowatt.
1 kilowatt	1.34 horsepower.
1 pound per square inch	2.31 feet of water.

SECTION VI

REQUIREMENTS AND EQUIPMENT

■ 227. REQUIREMENTS.—The water supply provided for civil consumption in most regions rarely is sufficient for military needs. It is estimated that when troops are massed for an advance, about 150,000 gallons of water are required per day per 20 square miles occupied. Table LXI gives per capita consumption of water under average conditions:

TABLE LXI.—*Daily water consumption in gallons*

NOTE.—These estimates must be modified according to circumstances, especially in hot climates. The requirements of the maximum month may exceed those of the average month by from 14 to 40 percent.

Unit consumer	Conditions of use	Gallons per unit per day	Remarks
Man (per capita consumption).	In combat:		
	Minimum	$\frac{1}{3}$ to $\frac{1}{2}$	For periods not exceeding 3 days.
	Normal	1	
	In bivouac:		
	Minimum	1	Drinking and cooking only, for periods not exceeding 3 days.
	Temporary camp:		
	Normal	5	Drinking, cooking, and washing.
	Temporary camp	15	Includes also bathing.
	General hospital	25	
	Semipermanent camp.	30	Includes also water for baths, toilets, etc.
	Permanent camp	50	
Horse or mule, large domestic animals (consumption per animal).	Minimum	3 to 5	For periods not exceeding 3 days.
	Normal	10	
Motors (consumption per vehicle).	Level and rolling country.	$\frac{1}{8}$ to $\frac{1}{2}$	Depends on size of vehicle.
	Mountainous country.	$\frac{1}{4}$ to 1	Depends on size of vehicle.
Locomotives (consumption per locomotive).	Standard military	33, 000	150 gallons per train mile.
	Commercial	50, 000	200 gallons per train mile.
Shower bath	Semipermanent buildings (consumption per fixture).	300	
Water closet	do	40	
Lavatory, basin or sink.	do	20	
Urinal	do	40	

■ 228. EQUIPMENT.—The distribution of water supply equipment to engineer units can be obtained from current Tables of Basic Allowances, Corps of Engineers.

SECTION VII

SUMMARY

■ 229. SUMMARY—*a*. Water is procured locally by using organizations wherever practicable. When local supplies are limited or unsatisfactory, engineer personnel install and operate such water supply facilities as are necessary.

b. Responsibility for the quality of water supplied to troops in the theater of operations to include delivery to the point where it is distributed to using organizations rests with the engineers, assisted as may be necessary for laboratory examination by attached medical personnel. The handling of water in organization water containers and sterilizing bags, and in the canteen of the individual enlisted man is a responsibility of the organization commander, acting with the advice and assistance of attached medical personnel.

c. Engineers, in cooperation with the Medical Department, should recommend to their tactical commanders the measures to be taken for enforcement of water discipline.

d. General engineer troops normally execute all engineer water supply tasks, except those involving the transportation of water by truck or railway and the operation of purification trucks. General engineer troops are responsible for making necessary water reconnaissances within their respective areas.

e. Wide dispersion of water supply establishments is effected wherever possible.

f. Water supply establishments require extensive camouflage measures.

g. A carefully developed plan of traffic control must be enforced at water supply points.

h. Water supply work in forward areas is taken over by engineers of rear echelons whenever time and existing conditions permit.

i. Several small water supply points will serve better than a few large ones.

j. All water, whatever the source, should be considered contaminated until it is tested and designated as safe. Regardless of contamination, however, water should be disinfected before being used for drinking purposes. Water suspected of being contaminated with gas or chemicals must not be used until passed by the Medical Department.

CHAPTER 8

ELECTRICITY

SECTION I

GENERAL

■ 230. MILITARY APPLICATION OF ELECTRICITY.—The providing of electricity by combat engineer troops in the field is usually limited to supplying lighting systems for their own units and for headquarters of divisions and higher units. Nondivisional or special engineer troops install electrical facilities for hospitals and depots, power systems for operating shops or portable electrical machinery, and facilities for other miscellaneous purposes.

■ 231. SOURCES OF ELECTRICITY.—As a general rule, the Army will use commercially produced power when the availability and characteristics of such power make it adaptable to the electrical machinery employed. In the field, all arms and services furnish power for their own uses.

■ 232. EQUIPMENT.—The items of light and power equipment procured and stocked for the use of the field forces are limited to special military items and some standard commercial items, including generator sets ranging from 1½ to about 750 kilowatts, motors ranging from ¼ to about 30 horsepower, single-phase transformers ranging from 5 to about 200 kilovolt-amperes, and other common articles of miscellaneous electrical equipment. Both alternating and direct current machines are used, depending principally upon the availability of suitable current and machines. For certain special purposes, such as antiaircraft searchlights, direct current is essential. In the case of the searchlights, the current is provided by a power unit for each light.

■ 233. STANDARD 5-KVA PORTABLE GENERATOR.—*a. Description.*—The standard 5-kva set is a portable alternating current generator.. Its source of power is a 4-cylinder gasoline engine. Both the engine and generator are mounted on a common base and are connected by two couplings and flexible discs. The unit is normally carried on a 1½-ton truck, and can be manhandled on and off by eight men, although skids and tackle are preferable. It is desirable that two men be detailed to operate this unit, although it is possible for one to do it alone.

b. Location.—A portable generator set should be located as near as possible to the load it supplies, and if possible, within a shelter where the attending personnel can live and do the work necessary to maintain the equipment.

c. Capacity.—Unless the transmission lines are very long, or the wires are not of proper size, it may be assumed for rough estimates that the 5-kva generator will supply from 100 to 115 40-watt lamps or their equivalent.

d. Manual.—The instruction manual issued with the unit covers details of its operation.

■ 234. USEFUL INFORMATION.—*a. Power in direct current circuits.*—In a direct current circuit, power in watts (W) is equal to electromotive force in volts (E) multiplied by current in amperes (I):

$$W=EI$$

b. Power in alternating-current circuits.—In alternating-current circuits, true power in watts (W) is equal to the product of the power factor in percentage (pf) by the electromotive force in volts (E) by the current in amperes (I):

$$W=(pf)EI$$

c. Ohm's law for direct-current circuits.—In direct-current circuits, the electromotive force in volts (E) is equal to the current in amperes (I) multiplied by the resistance in ohms (R):

$$E=IR$$

d. Units:

(1) *Kva.*—The unit used for measuring the apparent power of an alternating-current generator operating on circuits sub-

ject to change in power factor is the kilovolt-ampere. The following relationship exists:

$$\text{Kilovolt-amperes} = \frac{\text{volts} \times \text{amperes}}{1000}$$

(2) *Kw.*—The unit used for measuring true power in an alternating-current circuit is the kilowatt (*kw*). The following relationship exists:

kilowatts=kilovolt-amperes×power factor (*pf*).

(3) *Hp.*—The unit used for measuring mechanical work is the horsepower (*hp*). The following relationship exists:

1 *hp*=746 watts

(4) *Wire sizes.*—The unit used for measuring wire sizes is the mil. The following relationship exists:

1 mil=.001 inch

In tables, wire size is expressed in circular mils (cross-sectional area). The wire size in circular mils is the square of the diameter in mils.

Section II

MILITARY REQUIREMENTS

■ 235. Camp Lighting.—When camps are lighted there need not be more than four 25-watt lights per barrack (20 by 100 feet) and one 40-watt light per officer. In general, electric lamps should be provided in recreation halls.

■ 236. Lights for Division Headquarters.—The forward echelon of an infantry division headquarters requires about 75 lamps of 40- to 60-watt rating. This imposes a load of from 3 to 4½ kilowatts, depending on the actual wattage of the lamps used. One portable 5-kva generating set is adequate to supply this requirement.

■ 237. Lights for Higher Headquarters.—Experience indicates that for higher echelons the requirements in electric lighting are about as follows:

TABLE LXII.—*Electric light requirements for headquarters*

Headquarters	Approximate number of outlets to be furnished	Power in kilowatts required
Corps	75	4.5
Army	150	9.0
GHQ	600	36.0
Communications zone	600	36.0

■ 238. POWER AND LIGHTS FOR HOSPITALS.—A 1,000-bed hospital requires about 15 kilowatts for lights, sterilizing apparatus, dentists' tools, X-rays, etc. If possible, commercial sources of power should be used. A 250-bed station hospital requires about 5 kilowatts which can be supplied from a single portable 5-kilowatt generator.

SECTION III

RECONNAISSANCE

■ 239. RECONNAISSANCE PARTY.—*a. Personnel.*—The personnel of a party for making an electrical reconnaissance of an area to be occupied by a division normally should include a qualified leader and from three to six assistants familiar with transmission lines, primary power plants, and central station installations. Such individuals generally are classified as electrical engineers, general electricians, linemen, gas enginemen, or stationary enginemen.

b. Equipment.—The party should have adequate transportation and should be provided with maps of the area to be reconnoitered, paper and pencils for making reports, report blanks, and one or more sets of the following lineman's equipment: pole climbers with straps, tool belt with safety strap, splicing clamp, 8-inch side-cutting pliers, 24-inch bolt cutter, screw driver, hatchet, claw hammer, wrecking bar, hack saw, and high-tension gloves.

■ 240. GENERAL RECONNAISSANCE.—An electrical reconnaissance involves investigation of the source of the local supply of electricity and the amount of additional load which the existing facilities can carry. In order that military electrical equipment may be used, it is essential that the frequencies of the local source be the same as that for which the military equipment has been designed. The party should investigate the nature of the local supply (alternating or direct current), the frequencies used, and any existing facilities for modifying the frequencies, in order to adapt them to military equipment. The voltage at which the power is transmitted should be determined as well as the condition of the local installations and the system of operation and control. A very important consideration is to determine whether the local fuel situation is satisfactory, and if not, what steps are necessary to supply fuel to the local plants. The location and inventory of existing stocks of electrical supplies in the area should be determined, including wire and cable, incandescent lamps, motors, generators, poles, and accessories. If possible, a diagram should be obtained or made showing the distribution of electrical power throughout the area. An estimate should be made of the requirements in power in the new area and recommendation should be made covering the allocation of portable equipment, the installation of new equipment, and regulations for the consumption of light and power.

■ 241. Reconnaissance of Captured Terrain.—The reconnaissance of an area captured from the enemy is similar to that described above for the general reconnaissance of a new area, except that the enemy may be expected to destroy or damage the electrical installations prior to his departure. However, they should be carefully examined, since one usable installation may be made up from undamaged parts taken from several demolished plants. Particular note should be taken of the location and size of the conductors of any distribution lines remaining intact, as by making use of such systems the reestablishment of electric service in the captured area may be made in minimum time. Electrical supplies left in abandoned dumps should be inventoried.

■ 242. Blank Form.—The following blank form is suggested for use by a reconnaissance party both in making an electrical reconnaissance and in reporting the results.

ELECTRICAL RECONNAISSANCE

Reconnaissance party:

______________________	Area__________________	Date__________________
______________________	Map__________________	Photographs____________
______________________		

Prime movers	Generators	Transmission lines
Type: __________________ (Steam, internal combustion, water wheel)	Type__________________ (Alternating or direct current)	Type__________________ (2-wire; 3-wire Edison; 1, 2, 3, phase alternating current)
	Number of machines______	Current_____ Voltage_____ (Alternating current or direct current)
Fuel: __________________ (Coal, oil, gas)	Kilovolt amperes__________	Conductors______________ (Size and material)
	Kilowatts_______Volts_____	
____________________ (Amount on hand)	Amperes__ Power factor__	Location______________ (On poles or below ground)
	Frequency______________	
	Revolutions per minute___	
____________________ (Feed)	Horsepower__ Maker_____	Transformers____________
Horsepower______________	General condition_________	Substation______________ (Whether transformer or synchronous converter)
Lubricants______________ (Kind and amount on hand)	______________________	
	______________________	Condition______________
Water supply____________ (Character and amount)	______________________	______________________
General condition_________	SWITCHBOARD	ELECTRICAL SUPPLIES
______________________		Location______________
______________________	Instruments____________	General kind____________
______________________	Interconnections_________	Inventory______________
______________________	Condition______________	______________________

Recommendation____

____

FIGURE 128.—Form for electrical reconnaissance.

TABLE LXIII.—*Bill of electrical material for one standard 20-by-100-foot barrack*

Item	Quantity	Unit	Size	Weight in pounds	Description
1	210	feet	No. 14	5¼	Wire, R. C. S. B. solid copper.
2	1	each	125 volt, 30 ampere.	1	Cutout, main line, plug fuse, double pole.
3	2	each	15 ampere		Fuses, plug.
4	4	each		1¼	Socket, pull, brass, S22 (P&S) cat. 38, base BP.
5	50	each	No. 12	7½	Knobs, split porcelain, with nail and leather washer.
6	2	each	⅝ by 3 inches		Tubes, porcelain.
7	4	each	25 watts		Lamps, Mazda, 115-volt.
8	10	each	1½ inches		Screws, for cutout and socket, No. 8, F. H. bright.
9	4	each	3 feet		Cord, linen, with chain and link tassel.

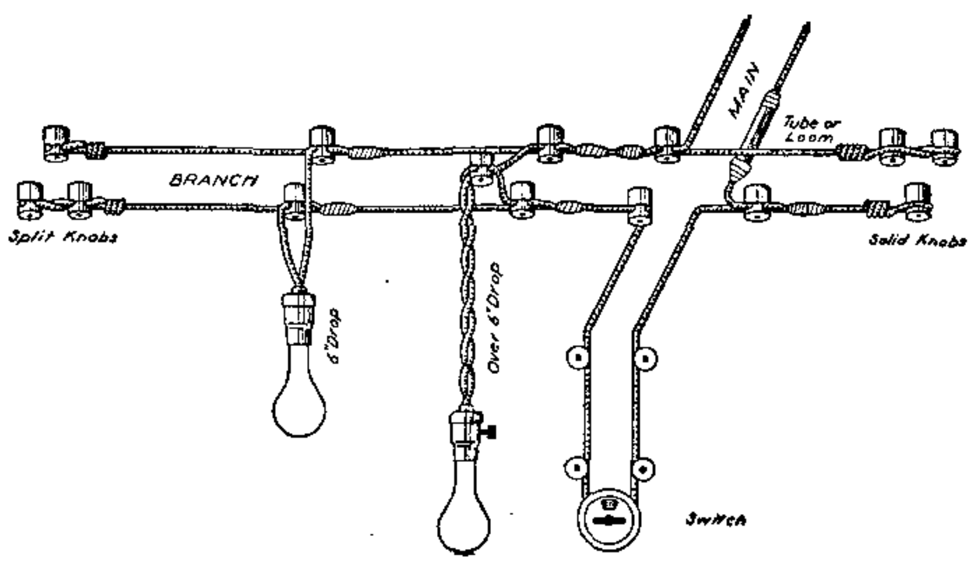


FIGURE 129.—Lighting installation using porcelain knobs.

TABLE LXIV.—*Electrical characteristics of copper wire*

Brown & Sharpe (B. & S.) gage	Cross section		Weight, resistance, and length			Safe current-carrying capacity in amperes for lengths of 100 feet or less	
	Diameter in mils	Area in circular mils	Pounds per 1,000 feet	Feet per pound	Ohms per 1,000 feet	Rubber insulation	Bare or weather-proof wire
0000	460.00	211,600	639.33	1.56	0.04906	225	325
000	409.64	167.805	507.01	1.97	.06180	175	275
00	364.80	133,079	402.09	2.49	.07831	150	225
0	324.95	105,592	319.04	3.14	.09831	125	200
1	289.30	83.694	252.88	3.95	.12404	100	150
2	257.63	66,373	200.54	4.99	.15640	90	125
3	229.42	52.634	159.03	6.29	.19723	80	100
4	204.31	41.742	126.12	7.93	.24869	70	90
5	181.94	33,102	100.01	10.00	.31361	55	80
6	162.02	26,250	79.32	12.61	.39546	50	70
*7	144.28	20,816	62.90	15.00	.49871	38	54
8	128.49	16,509	49.88	20.05	.62881	35	50
*9	114.43	13,094	39.56	25.28	.79281	28	38
10	101.89	10,381	31.37	31.38	1.0	25	30
*11	90.74	8,234	24.88	40.20	1.2607	20	27
12	80.81	6,530	19.73	50.69	1.5898	20	25
*13	71.96	5,178	15.65	63.91	2.0047	14	22
14	64.08	4,107	12.41	80.58	2.5908	15	20

Sizes marked * are not used for electrical work.

For aluminum wire the carrying capacity of any given size should be taken as 84 percent of the value given in above table.

If current exceeds the safe current-carrying capacity of the largest wire, two or more wires should be used.

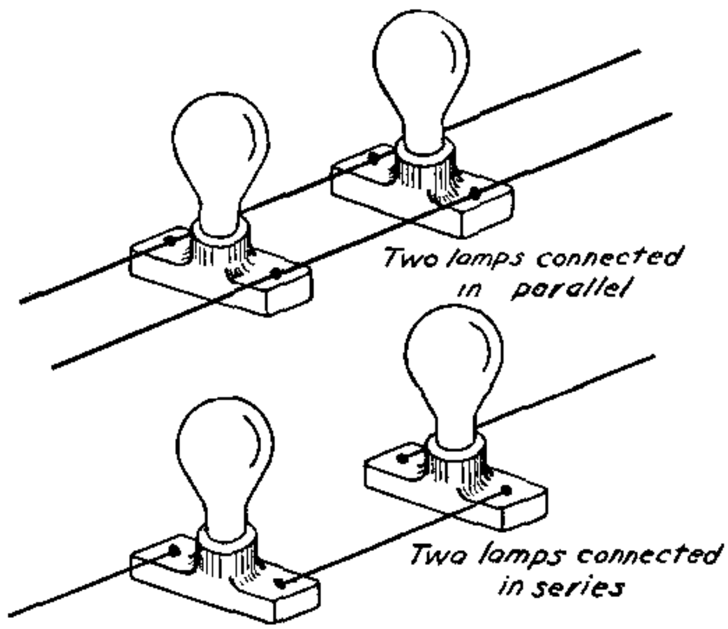


FIGURE 130.—Comparison of parallel and series circuits.

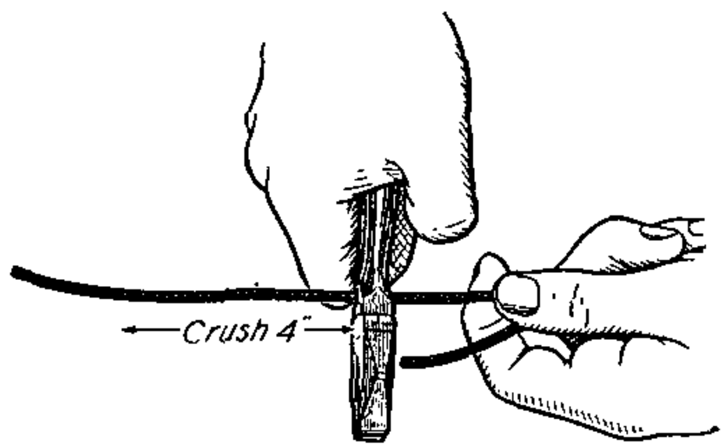


FIGURE 131.—Crushing insulation on long conductor.

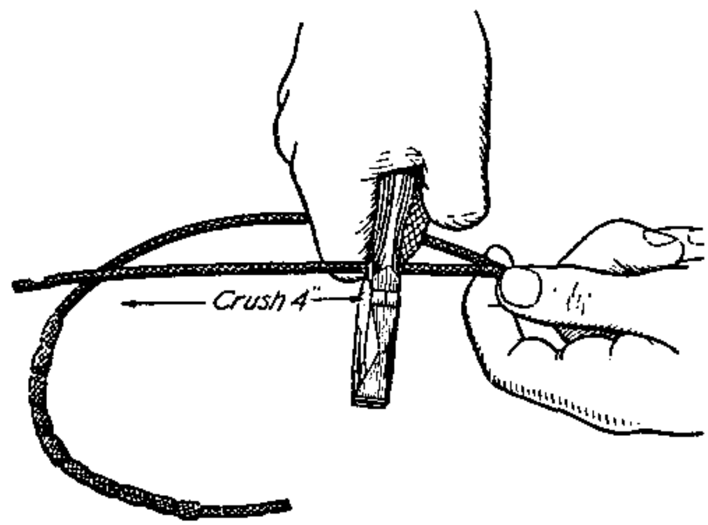


FIGURE 132.—Crushing insulation on short conductor.

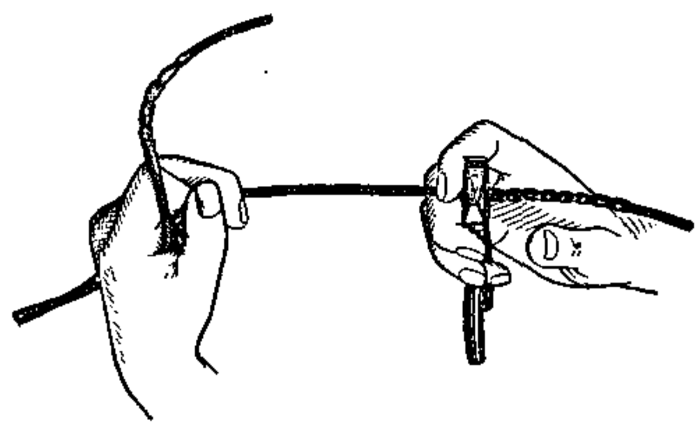


FIGURE 133.—Skinning conductor.

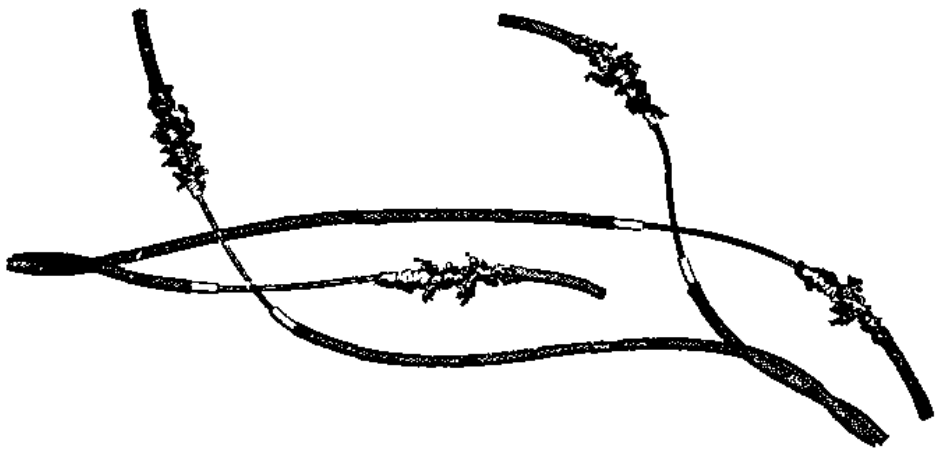


FIGURE 134.—Wires skinned and ready for square knots.

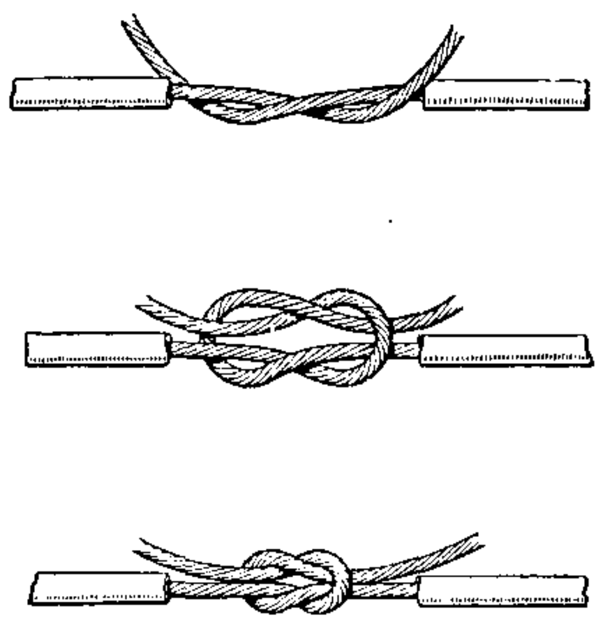


FIGURE 135.—Tying square knot.

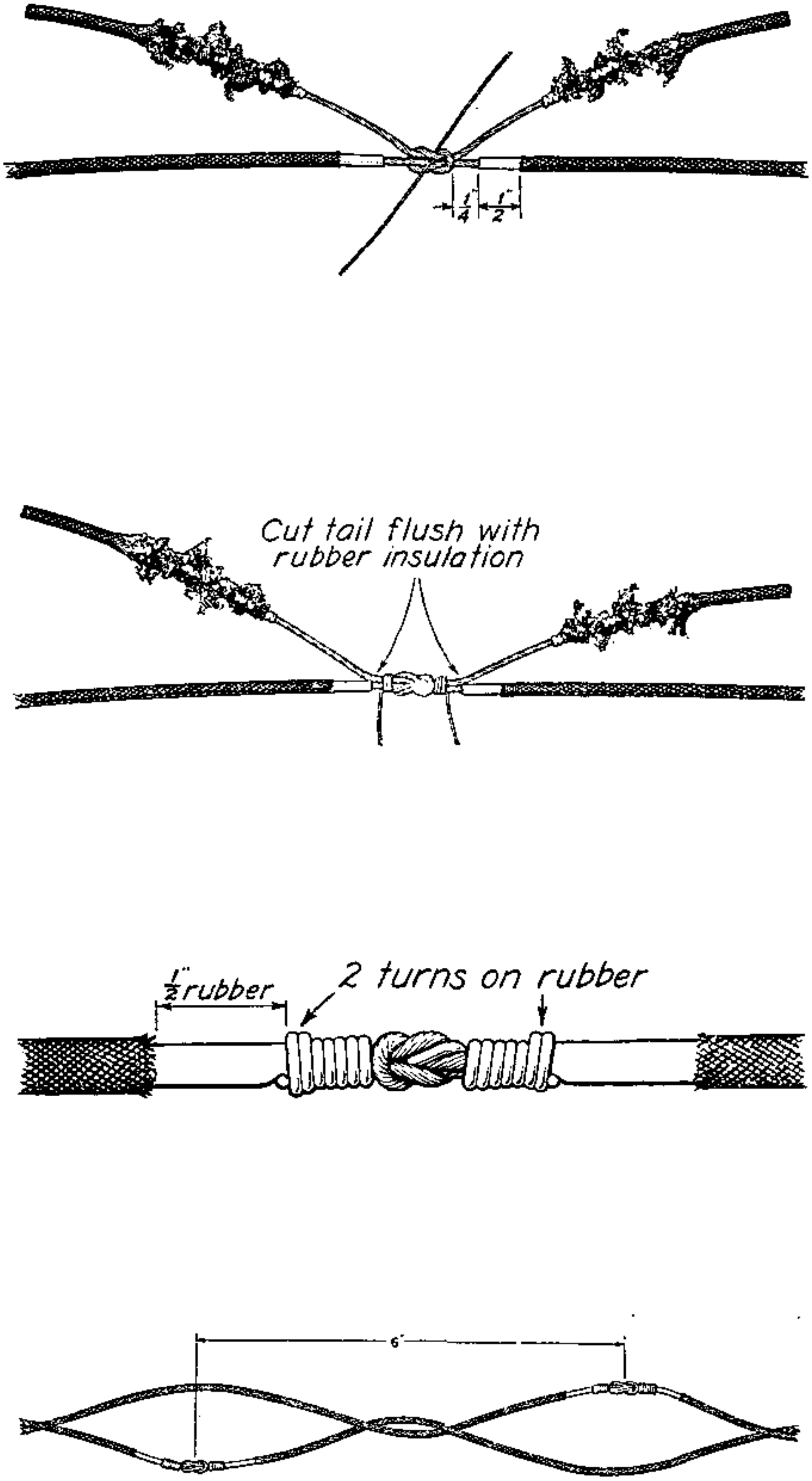


FIGURE 136.—Finishing the splice.

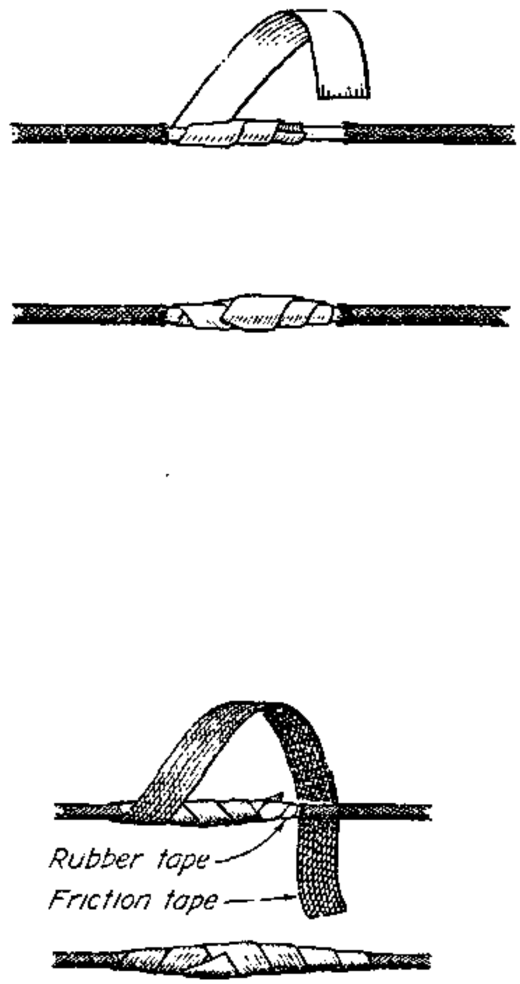


Figure 137.—Applying rubber and friction tape.

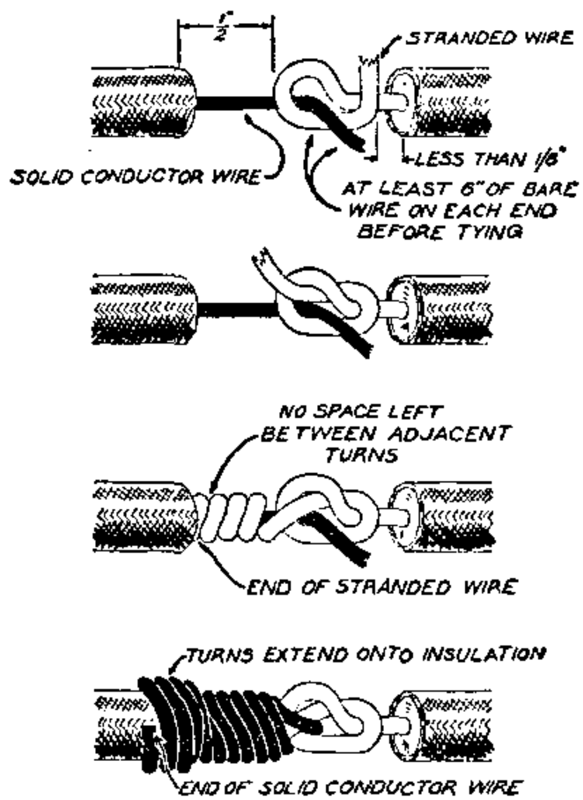


FIGURE 138.—Combination splice.

CHAPTER 9

RIGGING

■ 243. DEFINITIONS.—*a. General.*—Rigging involves the technique of handling manila and wire rope and chains in various block and tackle combinations to raise and move heavy loads. It is closely related to the handling of loads by jacks, levers, and similar mechanical devices.

b. Special terms.—(1) *Running end.*—Free end of rope.

(2) *Standing part.*—Whole rope less the running end.

(3) *Paying out.*—Giving slack in rope.

(4) *Bight.*—Loop formed on rope so that the two parts lie alongside each other or cross.

(5) *Frapping.*—Drawing together of several turns by passing a rope around all the turns.

(6) *Whipping.*—Wrapping an end tightly with cord or twine to prevent its unlaying when pulled through a pulley or other small opening.

(7) *Unlaying.*—Untwisting of the strands or cords.

(8) *Seizing.*—Lashing the running end back to the standing part.

(9) *Mousing a hook.*—Securing a load held in the hook by wrapping cord or twine across its mouth in such a way as to close it effectively.

(10) *Transom.*—Horizontal spar.

(11) *Upright.*—Vertical spar.

(12) *Belay.*—To make a turn or turns with a running end of rope around a spar, cleat, or the standing part of the rope.

(13) *Thief.*—Knot commonly mistaken for a reef knot, differing in that the end of each rope turns around the standing part, instead of around the end of the other rope.

(14) *Granny.*—Knot resembling a reef, except that the standing and running parts of each rope do not pass through the loop of the other in the same direction.

TABLE LXV.—*Characteristics of knots*

Name	Use	Directions for tying	Figure reference
1. Overhand	At end of rope to prevent unlaying or to prevent end from slipping through block.	See figure	139
2. Figure of eight	Same as above	See figure	139
3. Square or reef [1]	To join two ropes of same size.	See figure. Pass standing and running parts of each rope through loop of the other in same direction. Ends of each rope turn around end of other, rather than standing part.	139
4. Single sheet bend or weavers'.[2]	To join ropes, especially of unequal size.	See figure	139
5. Double sheet bend.[3]	To join ropes of unequal size, especially wet ones.	See figure	139
6. Two half hitches [4]	To belay or make fast end of rope around own standing part.	See figure. End may be lashed down or seized to standing part to prevent slipping.	139
7. Round turn and two half hitches.	Same as above	See figure	139
8. Fisherman's bend or anchor.	To fasten a rope to a ring or anchor.	See figure. Take two turns around the iron, then a half hitch round the standing part and between the ring and the turns, then half hitch round standing part.	139

[1] Care must be taken not to tie a thief or granny, as these will slip.
[2] More secure than a reef but more difficult to untie.
[3] More secure than a single sheet bend.
[4] Must never be used for hoisting a spar.

TABLE LXV.—*Characteristic of knots*—Continued

Name	Use	Directions for tying	Figure reference
9. Clove hitch	To fasten a rope at right angles to a spar or at beginning of lashing.	See figure. If end of spar is free, hitch made by first forming two loops, placing right-hand loop over other, and slipping the double loop over the end of the spar. Otherwise, pass end of rope round spar, bring it up to the right of standing part, cross over latter, make another turn around spar, bring up the end between spar, last turn and standing part.	139
10. Timber hitch [5]	To haul or lift spars	See figure	140
11. Telegraph hitch.	To hoist or haul a spar	See figure	140
12. Hawser bend	To join two large cables.	See figure. Each end is seized to own standing part.	140
13. Bowline [6]	To form a loop that will not slip.	See figure. Make loop with standing part underneath, pass end from below through loop, over the part, around the standing part, then down through the loop.	140
14. Bowline on a bight.	To make a comfortable sling for a man.	See figure. Make first part as above with double part of rope, then pull bight through sufficiently to allow it to be bent past loop and come up in proper position.	140
15. Running bowline.	To make a slip knot that will not bind.	See figure. Pass end around spar. Form a loop around the standing part with the running end. Make a bowline on the standing part below the loop—on the running-end side.	140

[5] Can be easily loosened when strain is taken off, but will not slip under load. When used for hauling spars, a half hitch is added near end of spar.

[6] Length of bight depends on purpose for which knot is required.

TABLE LXV.—*Characteristic of knots*—Continued

Name	Use	Directions for tying	Figure reference
16. Cat's paw	To secure a rope to the mouth of a hook.	See figure. Form two equal bights; take one in each hand and roll them along the standing part till surrounded by three turns of the standing part; then bring both loops (or bights) together and pass over the hook, and mouse the hook.	141
17. Sheep shank	To shorten a rope or pass a weak spot.	See figure. Take a half hitch with the standing parts around the bights.	141
18. Rolling hitch	To haul a larger rope or cable.	See figure. Take two turns around the large rope in the direction in which it is to be hauled, and one half hitch on the other side of the hauling part.	141
19. Blackwall hitch	To attach a single rope to a hook of a block for hoisting.	See figure	142
20. Mooring knot	To make fast to a mooring or snubbing post.	See figure. Take 2 turns around the mooring or snubbing post, pass the free end under the standing part, take a third turn above the other, pass the free end between the two upper turns.	142
21. Carrick bend	To fasten guys to derricks.	See figure	142
22. Wall knot and crown on wall.	To finish the end of a rope to prevent unlaying.	See figure	142

■ 244. SPLICES (fig. 143).—*a. Short splice.*—(1) *Use.*—Short splices are used to join two ropes when an increase in diameter at point of splice is not objectionable.

(2) *Directions for making.*—To make a short splice, unlay the strands of each rope for a convenient length. Bring the rope ends together so that each strand of one rope lies be-

tween the two consecutive strands of the other rope. Draw the strands of the first rope along the second and grasp with one hand. Then work a few strands of the second rope over the nearest strand of the first rope and under the second strand, working in a direction opposite to the twist of the rope. Apply the same operation to all strands. Splicing may be continued in the same manner to any extent, and the free ends may be cut off when desired. Splice may be tapered by cutting out a few fibers from each strand each time it is passed through the rope. Splice may be made compact by rolling under a board or under the foot.

b. *Long splice.*—(1) *Use.*—Long splices are used to join two ropes without an increase in diameter at point of splice.

(2) *Directions for making.*—To make a long splice, unlay the rope and bring together as for a short splice. Unlay to a convenient length a strand, *a*, of one rope, laying in its place the nearest strand, *d*, of the other rope. Repeat the operation in the opposite direction with two other strands, *c* and *f*. Lay half of one in place of the unlayed half of the other. Pass the tops through the rope. When the splice has been thoroughly stretched, trim off the ends of the strands.

c. *Eye splice.*—(1) *Use.*—Eye splices are used for fastening a rope to a ring or for making a permanent loop in the end of a rope.

(2) *Directions for making.*—To make an eye splice, unlay a convenient length of rope. Pass one loose strand under one strand of the rope, forming an eye of the proper size. Pass a second strand under the strand of the rope next to the strand which secures the first one. Pass the third strand under the one next to that which secures the second strand. Draw all taut, and continue as for a short splice.

■ 245. LASHING.—*a. Two spars at right angles* (fig. 144).—To lash two spars at right angles, make a clove hitch around the upright a few inches below the transom. Bring the lashing under the transom, up in front of it, horizontally behind the upright, down in front of the transom, and back behind the upright at the level of the bottom of the transom and above the clove hitch. Keep the following turns outside the previous ones on one spar and inside on the other, not riding over the turns already made. Make four more turns. Make two frapping turns between the spars, around the lashing, and finish the lashing off either around one of the spars or any part of the lashing through which the rope can be passed. Do not make the final clove hitch around the spar on the side toward which the stress is to come, as it may jam and be difficult to remove. While tightening, beat the lashing with a handspike or pick handle. This is called a square lashing.

b. Pair of shears (fig. 148).—To lash for a pair of shears, lay the two spars alongside each other with the points below which the lashing is to be made resting on a skid. Make a clove hitch around one spar, and take the lashing loosely eight or nine turns about the two spars, above the clove hitch, without riding. Make two or more frapping turns between the spars, and finish the lashing off with a clove hitch above the turns on one of the spars. Open the butts of the spars and pass a sling over the fork. Hook or lash a block to this sling. Make fast fore and back guys with clove hitches to each spar just above the fork.

c. Three spars for tripod (fig. 146).—To lash three spars together as for gin or tripod, mark on each spar the location of the center of the lashing. Lay two of the spars parallel to each other with an interval a little greater than the diameter. Rest their tips on a skid and lay the third spar between them with its butt in the opposite direction so that the marks on the three spars will be in line. Make a clove hitch on one of the outer spars below the lashing and take eight or nine loose turns around the three. Take a couple of frapping turns between each pair of spars in succession and finish with a clove hitch on the central spar above the lashing. Pass a sling over the lashing and the tripod is ready for raising.

■ 246. ANCHORAGES.—*a. Holdfasts* (fig. 147 ①).—(1) *Use.*— Holdfasts are used to anchor a line to the ground, as for a guy.

(2) *Directions for making.*—To make a holdfast, drive stout pickets into the ground, one behind the other, in the line of pull. Secure the head of each picket, except the last, by a lashing to the one behind it. Tighten the lashings by rack sticks, and then drive the points of these into the ground to hold them in position. The distance between pickets should be several times the height of the picket above the ground. A single good ash picket, 3 inches in diameter, driven 5 feet into good solid earth, will stand a pull of about 700 pounds.

b. *Deadman* (fig. 147 ②).—(1) *Use.*—Deadman has the same use as a holdfast except that it has greater strength, although requiring more labor.

(2) *Direction for preparing.*—To prepare a deadman, lay a log or timber in a transverse trench with an inclined trench intersecting it at its mid point. Pass the cable down the inclined trench, take several turns around the log, and fasten the cable to the log by half hitches and marline stopping. If the cable is to lead horizontally or incline downward, pass it over a log at the outlet to the inclined trench. If the cable is to lead upward, the log is not necessary, but the deadman must be buried deeper. The strength of the deadman depends upon the strength of the log and holding power of the earth.

(3) *Holding power.*—(*a*) The holding power per square foot of undisturbed loamy earth against a deadman at various depths and inclinations of cable pull is given in table LXVI below. For a given cable pull the number of square feet of deadman bearing surface required is determined by dividing the total pull to be placed on the deadman by the value given for the depth and cable inclination selected. Having determined the bearing-surface area, select a length and section corresponding to this area.

TABLE LXVI.—*Holding power of deadmen in loamy soil*

Mean depth of anchorage	Declination of pull (vertical to horizontal) and safe resistance in pounds per square foot				
	Vertical	1/1	1/2	1/3	1/4
3 feet	600	950	1,300	1,450	1,500
4 feet	1,050	1,750	2,200	2,600	2,700
5 feet	1,700	2,800	3,600	4,000	4,100
6 feet	2,400	3,800	5,100	5,800	6,000
7 feet	3,200	5,100	7,000	8,000	8,400

(*b*) In order to insure that the deadman selected will not fail in bending stress, test by:

$$T=\frac{2667bh^2}{L} \text{ for a rectangular timber.}$$

$$\text{or } T=\frac{1600d^3}{L} \text{ for a round timber.}$$

where T=maximum allowable cable pull in pounds.
b=width of the contact face of the deadman, in inches.
h=depth of deadman in direction of pull, in inches.
d=diameter of round timber, in inches.
L=length of deadman, in inches.

(*c*) If the maximum allowable pull, T, as computed, is less than actual pull, a timber of greater depth or diameter should be used, and test computation repeated until a satisfactory section is determined. If maximum allowable pull found by the formula is greater than the required cable pull, the deadman is satisfactory in bending.

■ 247. BLOCKS AND TACKLES.—*a. General.*—The parts of a block are the shell or frame, the sheave or wheel upon which the rope runs, and the pin upon which the wheel turns in the shell. Blocks are designated by the length of the shell in inches and by the number of the sheaves. Those with one, two, three, or four sheaves are called single, double, triple, and quadruple. The smallest size of block (length in inches) that will take a given rope is nine times the rope diameter. Self-lubricating blocks should be used where obtainable.

b. Definitions.—(1) *Snatch block.*—A snatch block is a single block with the shell open at one side to admit a rope without passing the end through.

(2) *Running block.*—A running block is attached to the object to be moved.

(3) *Standing block.*—A standing block is fixed to some permanent object.

(4) *Simple tackle.*—A simple tackle consists of one or more blocks rove with a single rope.

(5) *Return.*—Each part of the rope between the two blocks, or between either end and the block, is called a return.

(6) *Overhaul.*—To overhaul is to separate the blocks.

(7) *Round in.*—To round in, to bring the blocks closer together.

(8) *Chockablock.*—When the blocks are in contact the tackle is said to be chockablock.

c. Uses.—Blocks are used to change the direction of pull and to give mechanical advantage. A man of average weight will pull about 60 pounds horizontally.

d. Mechanical advantage.—In simple tackles the mechanical advantage gained is a direct function of the number of ropes supporting the load. Thus, if the movable block is a double one, then four ropes will sustain the load and the mechanical advantage gained is 4.

■ 248. SLINGS.—*a. General.*—Slings are made of manila rope, wire rope, or chains. The most common is a manila sling made by splicing the two ends together. To use the sling, pass it around the article to be lifted. Pass the bight formed by one end through the bight formed by the other and then over the lifting hook. If the sling is the same size as the lifting rope, it should make a minimum angle of 30° with the horizontal. At this angle, the stress in each branch of the sling is equal to the stress in the lifting rope. If the angle is greater than 30°, the load is limited by the strength of the lifting rope; if less than 30°, by the strength of the sling.

b. Barrel slings (fig. 141).—To sling a barrel horizontally, make a bowline with a long bight. To sling a barrel vertically, make an overhand knot on top of the two parts of the rope; open out the knot and slip each half of it down the sides of the barrel; secure with a bowline.

■ 249. GIN POLE OR STANDING DERRICK (fig. 149).—To erect a gin pole, lash the tackle to the spar or suspend it by a sling run through a slot in the head of the pole. Locate the foot of the gin pole. Lay a line through the point to mark the location of the fore and back guys. Lay another line at right angles to this. Lay off on the four lines distances equal to twice the length of the spar for level ground plus necessary slope allowances. Erect anchorages at these points. Make the four guys fast to the top of the spar. Lay the spar along one of the guy lines with the butt nearly in the footing. Fasten a foot rope to the butt and to an anchorage on the same side of the footing as the spar. Raise the top by hauling the back guy with a running tackle. Let the fore guy out. Take up the slack on the side guys. Continue until spar is in position, keeping the slack out of all guys. For heavy poles it may be necessary to erect a light gin pole or shears first and use this to erect the heavy pole. In hard ground dig a hole about 1 foot deep for the butt of the gin pole. In soft ground, prepare an excavation with wooden supports to transmit the ground pressure over a larger area.

■ 250. JACKS.—*a. Hydraulic jacks.*—The hydraulic jack is a lifting apparatus operated by means of a liquid acting against a piston or ram working in a cylinder. The pressure in the liquid is produced by a force pump. The lifting capacities of hydraulic jacks are usually stamped on their sides.

b. Screw jacks.—Screw jacks are of various types and sizes. They all depend on the screw principle for their gain in power. The lift of the jack is usually from 16 to 18 inches, and care should be taken that it is not screwed too high.

c. Use of blocks.—In raising heavy loads above the effective range of a single jack, blocks may be used to advantage along with additional jacks. One jack having lifted the load to the limit of its range, a second is inserted upon blocks (or with blocks between it and the load) and is raised. Then the first jack is blocked, the load raised another increment, and the operation continued. Several jacks may be used instead of one in each stage of the lifting. Lowering a load is the reverse of the above process.

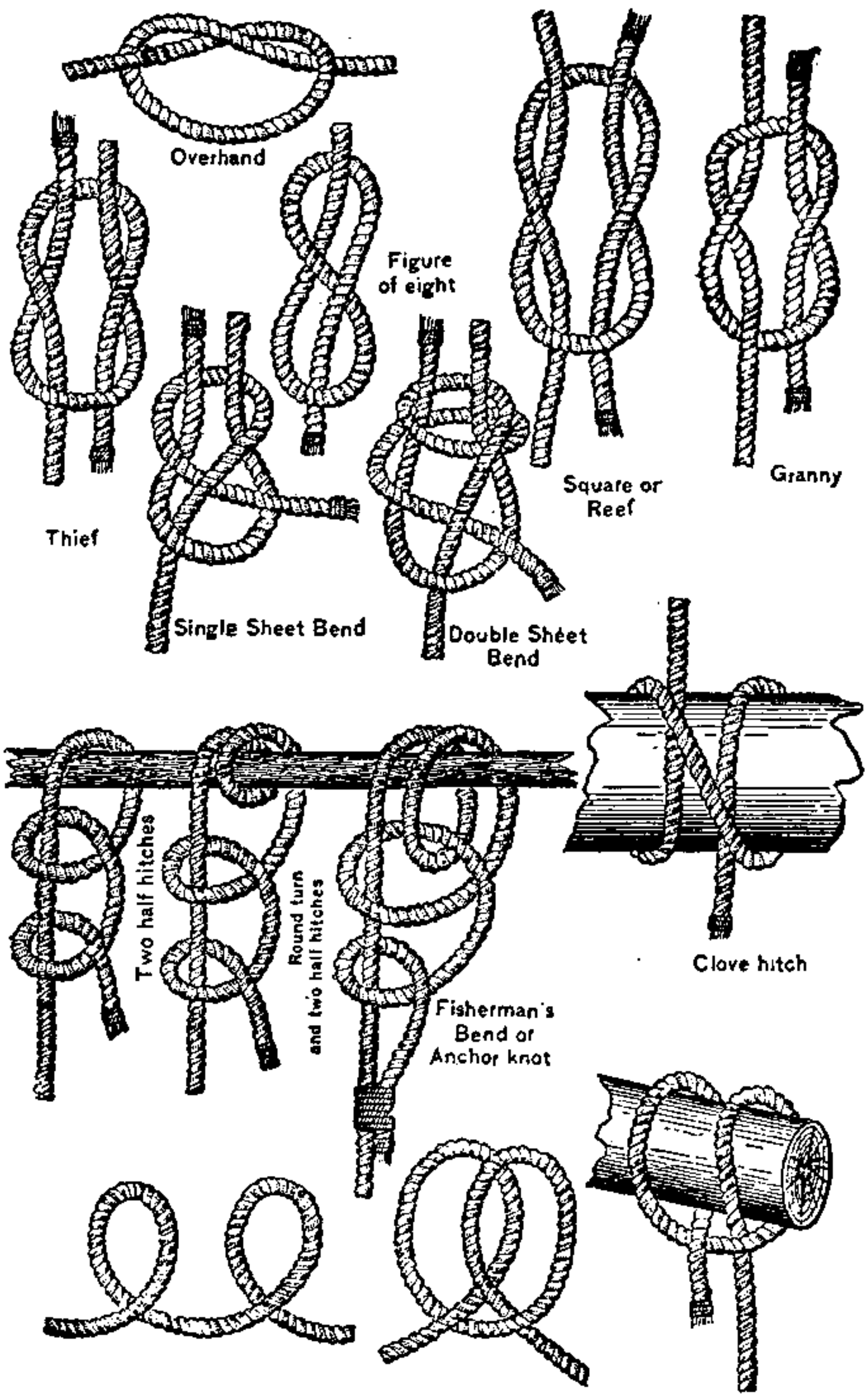


FIGURE 139.—Types of knots—hitches, bends, overhand, etc.

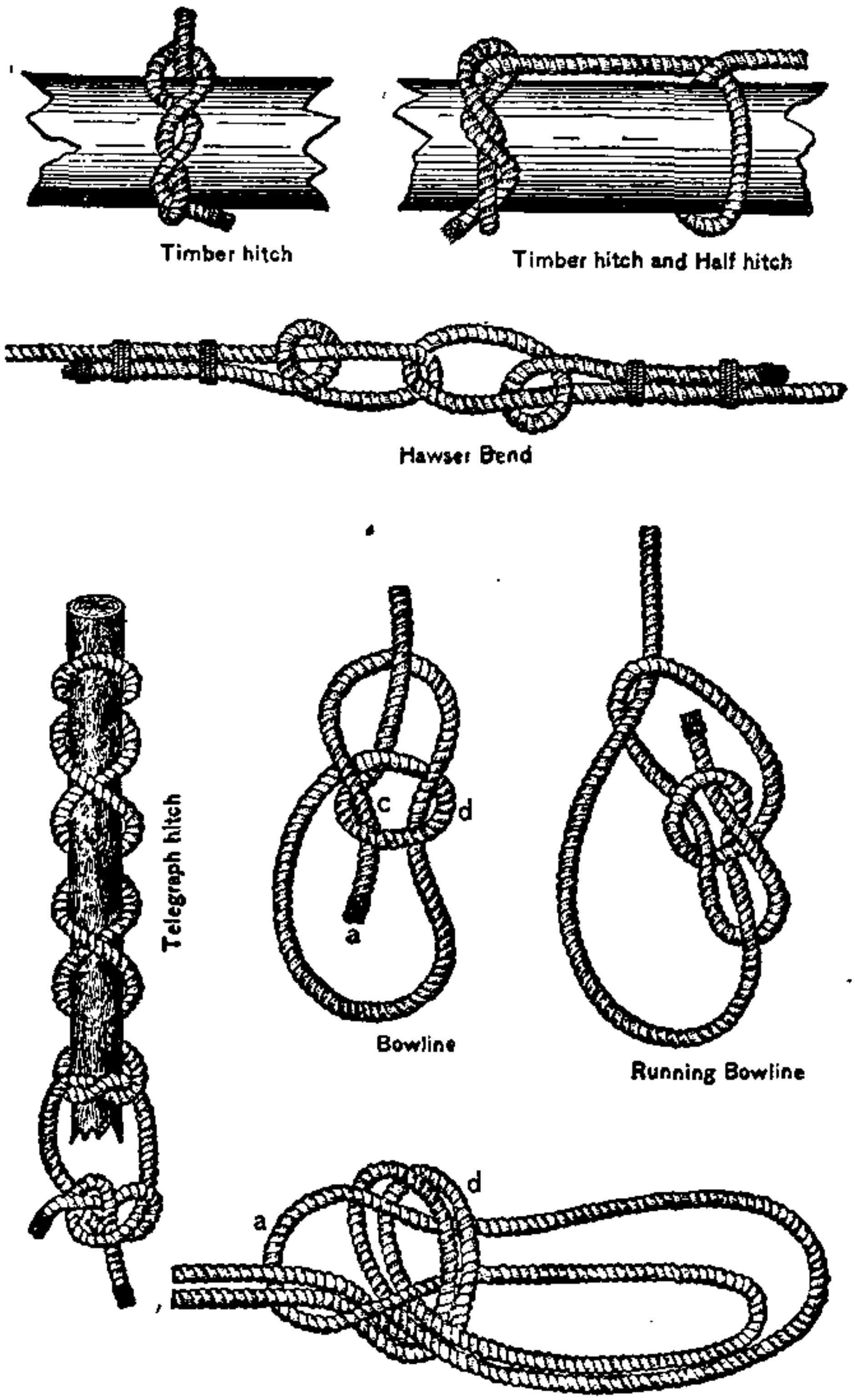


FIGURE 140.—Types of knots—hitches, bends, and bowlines.

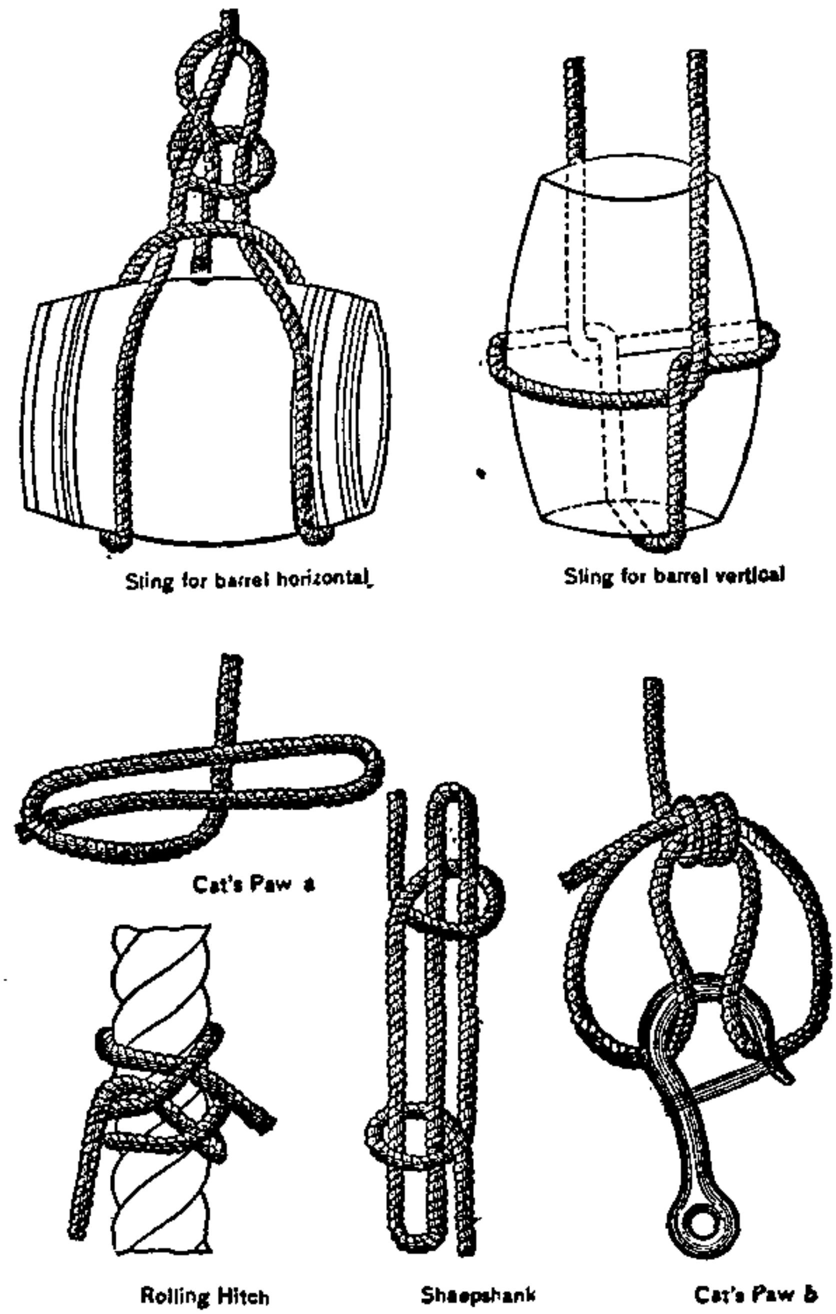


FIGURE 141.—Miscellaneous knots.

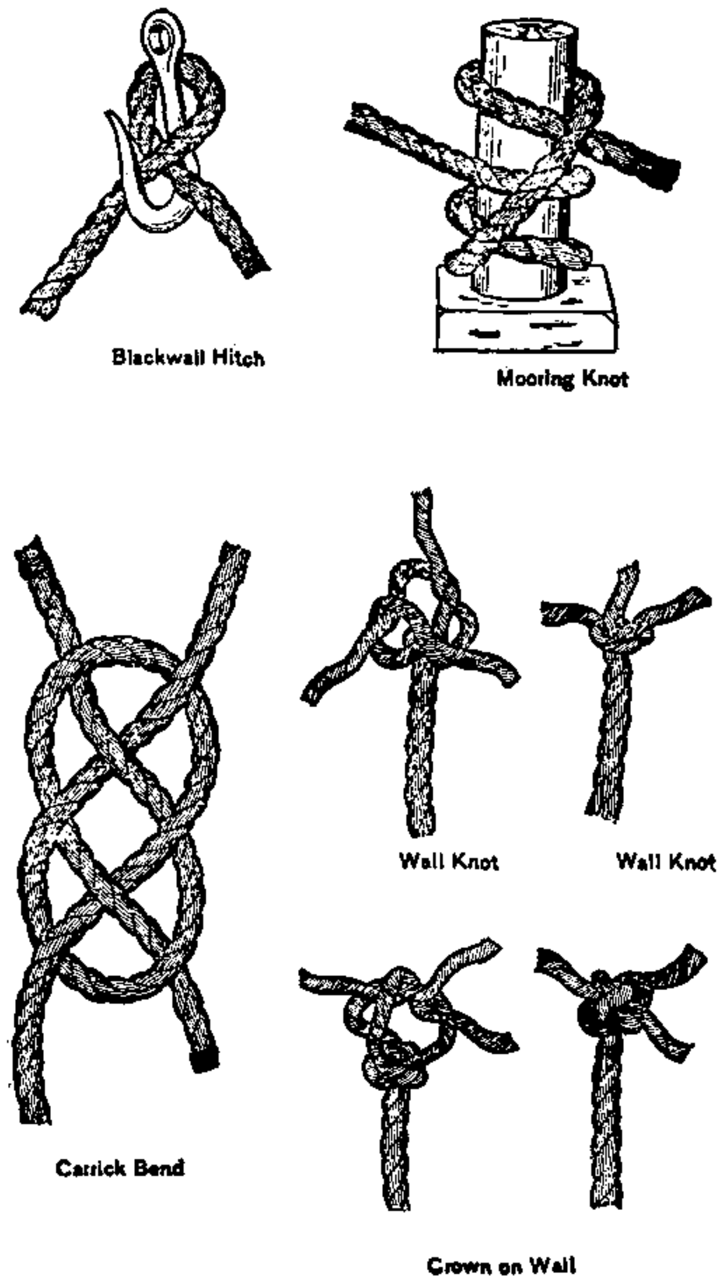


FIGURE 142.—Miscellaneous knots and hitches.

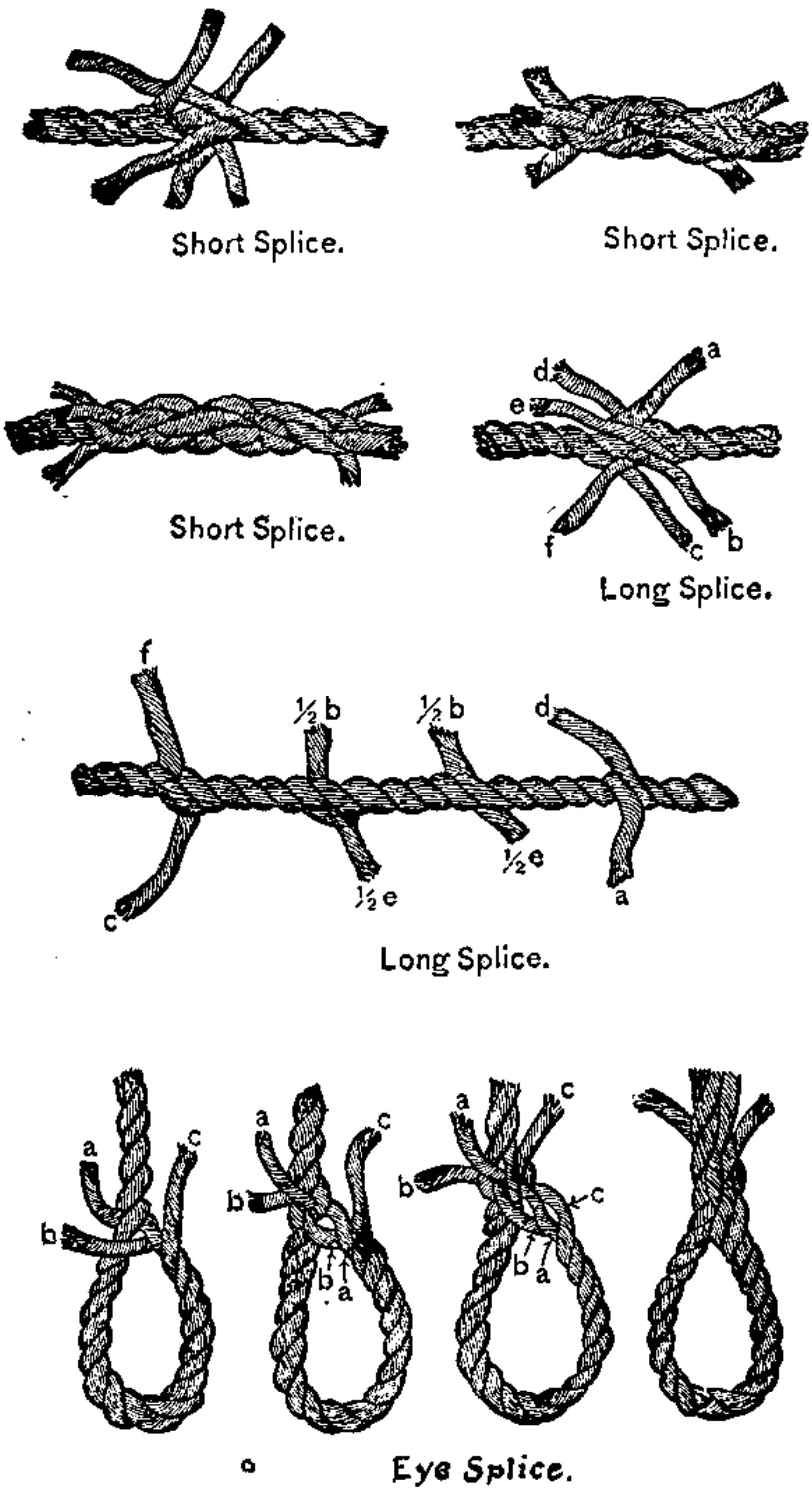


FIGURE 143.—Splices.

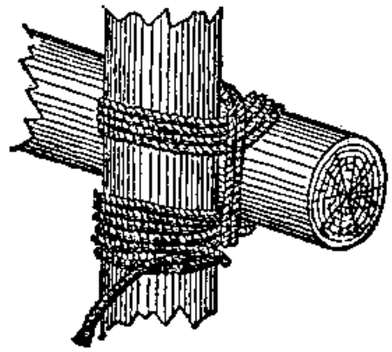


FIGURE 144.—Square lasning.

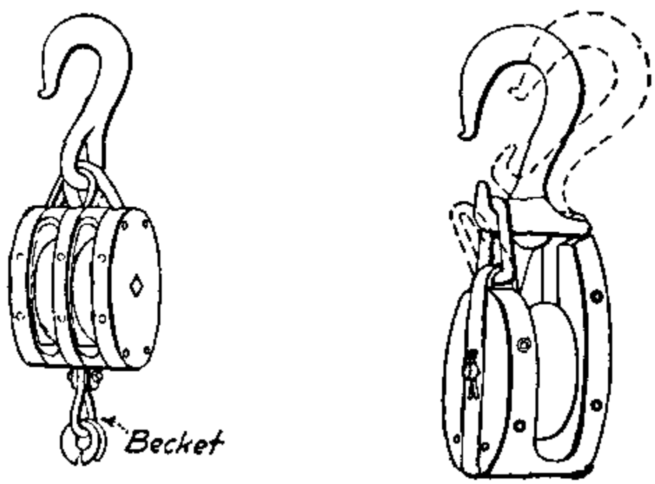


FIGURE 145.—Double wooden block and snatch block.

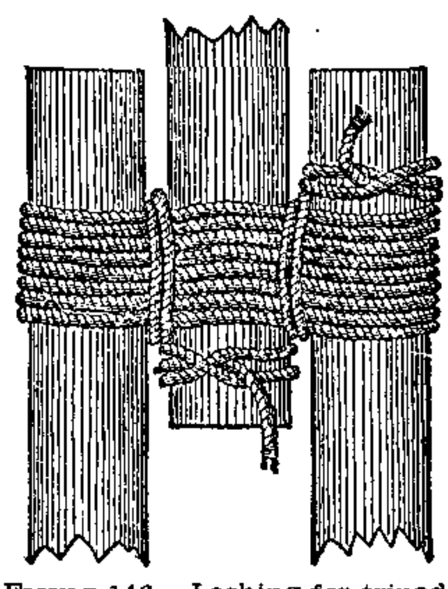
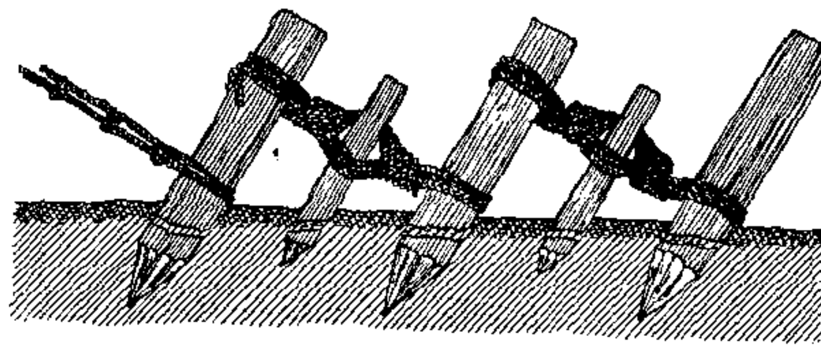
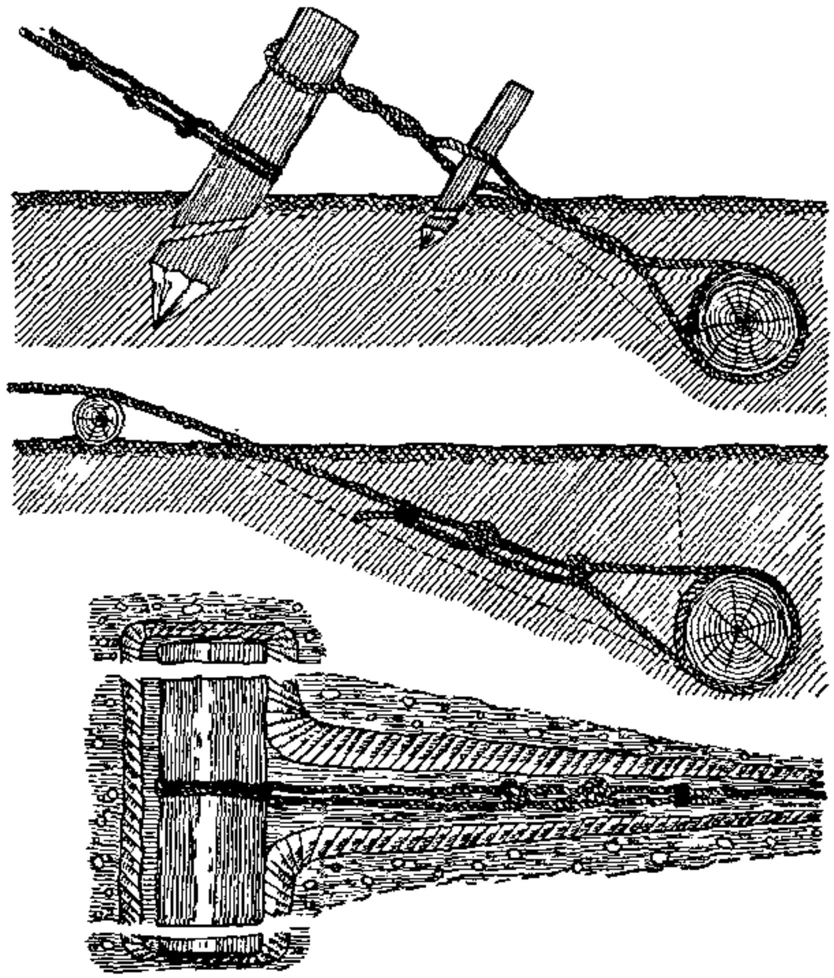


FIGURE 146.—Lashing for tripod.



Holdfasts.



Deadman.

FIGURE 147.—Anchorages.

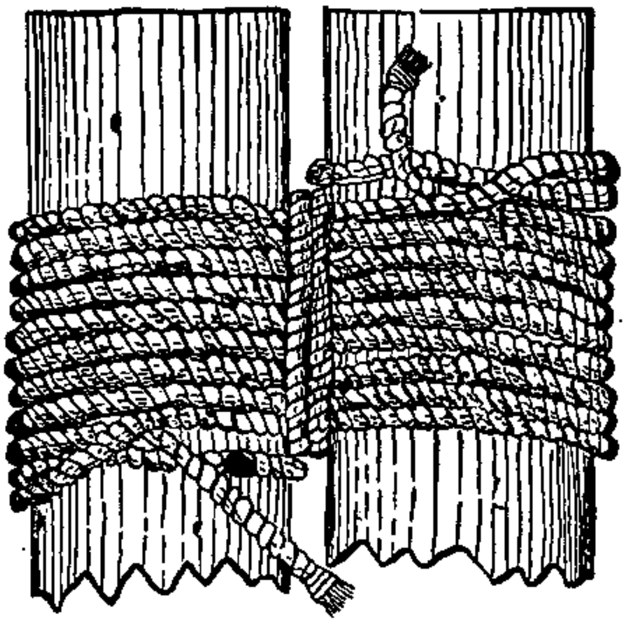


FIGURE 148.—Lashing for shears.

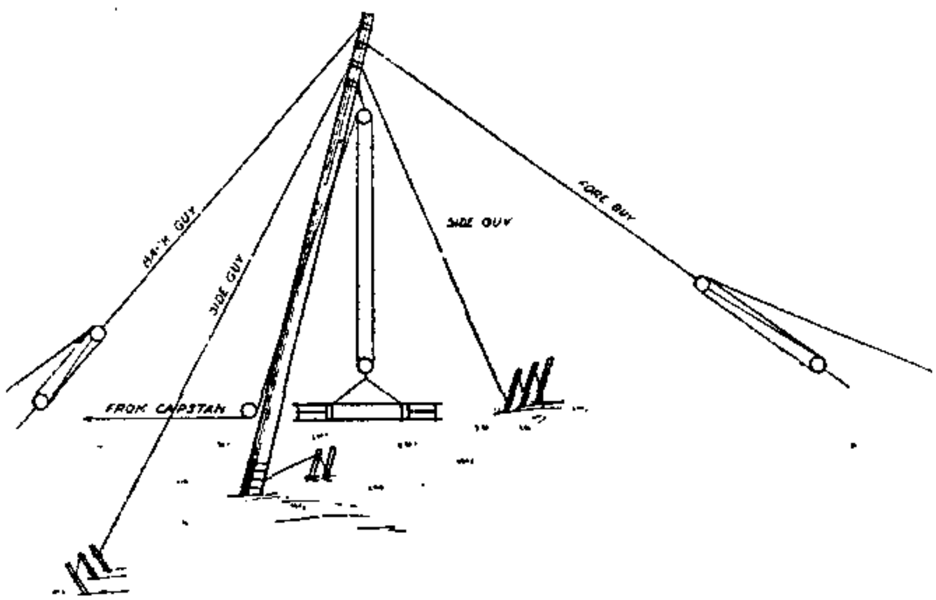


FIGURE 149.—Gin pole.

TABLE LXVII.—*Working strength of wire and manila rope*

Diameter	Circumference	Weight per 100 feet		Working strength (pounds)	
		Steel	Hemp	Steel	Manila or hemp
3/8	1 1/4	13	5	4,000	400
1/2	1 1/2	39	7	7,000	850
5/8	2	60	13	11,100	1,520
3/4	2 3/8	88	17	15,300	1,900
7/8	2 3/4	120	24	20,700	2,300
1	3 1/8	158	28	28,000	3,100
1 1/4	4	250	46	42,000	4,300
1 1/2	4 3/4	365	64	58,700	5,900
1 3/4	5 1/2	525	84	76,000	7,900
2	6 1/4	632	115	96,000	10,300
2 1/2	7 7/8	988	117	110,000	16,500
3	9 1/2	1,421	255	116,000	22,500

TABLE LXVIII.—*Relation of sheave and wire rope diameters*

Type of rope	Desirable sheave and drum diameter [1]	Safe sheave and drum diameter	Minimum sheave and drum diameter	
6 by 7 [2]	72	42	28	×rope diameter.
6 by 19	45	30	20	×rope diameter.
6 by 37	27	18	14	×rope diameter.
8 by 19	31	21	16	×rope diameter.

[1] For standing ropes, these values may be reduced by 50 percent.
[2] A 6 by 7 rope is one of 6 strands of 7 wires each.

TABLE LXIX.—*Lead line pull factors and efficiencies for hoist or full wire ropes*

Number of parts of rope	2	3	4	5	6	7	8	9	10
Efficiency, percent	96.1	92.4	88.9	86.5	82.2	79.0	76.0	73.0	70.3
Lead line pull factor	.52	.36	.28	.23	.20	.18	.165	.15	.14

NOTE.—The stress in the lead line equals the load multiplied by the lead line pull factor.

TABLE LXX.—*Simple block and tackle rigging manila rope (factor of safety 3)*

Load to be lifted	Total number of sheaves in blocks	2 (2 single blocks)	3 (1 single 1 double)	4 (2 double blocks)	5 (1 double 1 triple)	6 (2 triple blocks)
Tons						
½	Smallest permissible rope diameter (inch)	½	7/16	⅜	⅜	⅜
	Lead line pull, in pounds	540	380	300	250	220
1	Rope (inch)	¾	⅝	½	½	½
	Pull	1,100	760	600	500	440
1½	Rope (inch)	⅞	¾	⅝	⅝	½
	Pull	1,600	1,100	900	750	660
2	Rope (inches)	1⅛	⅞	¾	⅝	⅝
	Pull	2,200	1,500	1,200	1,000	880
3	Rope (inches)	1 5/16	1⅛	1	⅞	¾
	Pull	3,300	2,300	1,800	1,500	1,300
4	Rope (inches)	1½	1¼	1⅛	1	1
	Pull	4,400	3,000	2,400	2,000	1,800
6	Rope (inches)	--------	1½	1 5/16	1¼	1⅛
	Pull	--------	4,500	3,600	3,000	2,600
8	Rope (inches)	--------	--------	1⅝	1½	1 5/16
	Pull	--------	--------	4,800	4,000	3,500

TABLE LXXI.—*Properties of chains*

Size (inches)	Safe working strength (pounds)	Approximate weight (pounds per 100 feet)
3/8	1,800-3,000	175
7/16	2,500-3,800	230
1/2	3,300-5,000	300
5/8	5,000-7,600	470
3/4	8,000-11,000	650
7/8	10,000-15,000	880
1	12,000-20,000	1,130
1 1/8	16,000-26,000	1,420
1 1/4	19,000-32,000	1,650

NOTE.—Chains are manufactured in such a wide variety of grades that no definite strength can be given for any one size. The above are limits for some standard sling and dredge chains.

CHAPTER 10

CONCRETE AND QUARRY OPERATIONS

SECTION I

CONCRETE

■ 251. MILITARY USES OF CONCRETE.—*a. General.*—The military uses of concrete may be classed under two general heads:

(1) *For field works subject to artillery fire and air bombing.*—These include shelters for machine guns and artillery, dug-outs, cut and cover and surface shelters, burster courses, command and observation posts, platforms for heavy ordnance, etc.

(2) *For general construction in rear areas.*—These include a great variety of structures generally similar to those erected in civil practice.

b. Military vs. *civilian practices.*—In time of peace the best civilian practices in concrete construction are rigorously observed in military work. Even in time of war it is highly desirable that military concrete construction follow the same basic principles, altered only insofar as economy of time and materials and the military situation require. In forward areas it may sometimes be necessary to use materials and expedients which would not be permitted under normal circumstances. Superficial refinements such as exact control of aggregates, finishing surfaces, drying of aggregates, etc. are not essential in the wartime military use of concrete, and may be omitted. However, it must be emphasized that concrete may be of little strength or value unless care is used in designing, mixing, placing, and curing the concrete.

■ 252. CEMENT.—*a. Classes.*—The substance which gives strength to concrete and binds the aggregates together is known as cement. Although there are many types of cement, the classes most commonly used in military work are—

(1) *Standard Portland.*—Standard Portland cement should be used for all works subject to artillery fire, shock, abrasion, etc., and for all reinforced concrete when there is sufficient time available. However, its chief disadvantage for wartime military construction is the length of time necessary for concrete made with it to develop its normal compressive strength.

(2) *High early strength cements.*—This class includes modified portland cements and high alumina cements, which combine the properties of standard Portland with high early strength. Concrete made with this type of cement will attain in from 1 to 2 days 75 percent of the strength attained in 28 days by a concrete made with standard Portland. This property makes these cements very desirable for military construction in time of war, where the time element is of great importance. However, they have the disadvantage of being more expensive and less readily available commercially.

b. Shipment and storage.—Cement is usually shipped in bags or barrels. A bag of cement weighs 94 pounds and is considered to be 1 cubic foot. A barrel contains four bags. Cement should be stored in a weatherproof building at least 8 inches from walls and ground or floor to insure ventilation.

■ 253. FINE AGGREGATE.—*a. Definition.*—Aggregate is the inclusive term applied to the inert materials which, bound together with cement, make concrete. That portion of the aggregate which passes a 3/8-inch screen is called *fine aggregate.*

b. General requirements.—(1) *Durability.*—Sand should be composed of hard, strong, durable, and uncoated particles. Sand of natural origin is ordinarily used. However, crushed stone screenings make acceptable sand if the rock from which they are crushed is suitable. Sands from soft parent rocks, such as slate, serpentine, mica, feldspar, and soft limestone should not be used. nor should sand be composed of mica, talc, or scaly materials.

(2) *Cleanliness.*—(*a*) Clay and silt, the impurities most frequently found in sand, are undesirable if present as coatings on the sand grains. If present in the sand, they should constitute not more than 3 percent of the sand by weight, or, together with coal particles, shale, shell, or other deleterious

substances should constitute not more than 5 percent by weight. A convenient field test for the presence of silt and clay in excess quantities follows: Fill a pint jar to a depth of 4 inches with sand and then fill almost full with water. Shake for several minutes. If there is more than ¼ inch of sediment on top of the sand after settling, the sand is unsuitable even for lean mixtures.

(*b*) Organic material, that is, material of animal or vegetable origin, in sands not only prevents the cement from adhering but also affects it chemically. Sands containing roots, grass, leaves, grease, tannic acid, etc., must not be used unless washed. A convenient test for organic impurities in sand is as follows: Fill a bottle half full with the sand to be tested. To it add a 3-percent solution of sodium hydroxide until the volume of sand and water after shaking amounts to 1½ times the original volume of sand alone. Shake thoroughly and allow to stand for 24 hours. If the liquid above the sand is colorless or light yellow, the sand is satisfactory as far as organic impurities are concerned. If bright yellow or medium brown, the sand may be used for unimportant work. If the liquid is darker than medium brown, the sand should not be used in concrete.

(*c*) Sand may be washed by hand or mechanical means. One convenient method is to place the sand on a wire screen with mesh similar in size to that used in screen doors, and wash with water.

(3) *Gradation*.—The best sand, as to size, is one which is well graded from fine to coarse. If only a sand of uniform size is available, a coarse sand is better than fine sand. Table LXXII gives a suitable gradation for fine aggregates.

TABLE LXXII.—*Gradation of fine aggregates*

	Percent by weight
Passing ⅜-inch (standard square mesh)	100
Passing No. 4	95–100
Passing No. 16	35–75
Passing No. 50	10–25
Passing No. 100	2–7

(4) *Screening.*—Hand screening is best adapted to small jobs. Set up screens with openings of the desired size at about 60° with the horizontal and then shovel the material upon the screen. The finer particles will pass through, while the larger ones will roll down the inclined screen.

■ 254. COARSE AGGREGATE.—*a. Definition.*—Coarse aggregate is that part of the materials in concrete which will not pass through a $\frac{3}{8}$-inch screen, such as gravel, crushed rock, etc.

b. General requirements.—(1) *Materials.*—Coarse aggregates must be dense, hard, and durable. The most common kinds of coarse aggregates are broken stone, gravel, slag, and cinders.

(*a*) Aggregates derived from granite or trap rock are usually excellent, while those from limestone are generally satisfactory. Sandstone with a clay binder makes the least desirable aggregate.

(*b*) Gravel is a natural mixture of pebbles, silt, and clay, with pebbles predominating. It must be clean and durable to be suitable for concrete work. The use of bank-run gravel is condemned in civil practice, but will often be necessary in some types of military operations because of the great saving of plant, time, and labor involved. Good results can be obtained if the pit is properly selected and worked. Washing and screening are often necessary. The usual fault of bank-run gravel is an excess of coarse aggregate. This may be corrected by the addition of fine aggregate screened from another section of the pit.

(*c*) Slag from blast furnaces, crushed to proper sizes, makes a fairly satisfactory coarse aggregate for mass construction if it is free from sulphur.

(*d*) Cinders may be used in inferior grades of mass concrete or in concrete used for fireproofing structural members where lightness and little strength are required.

(2) *Gradation.*—Screened coarse aggregate of a single size should not be used. Proper gradation of sizes is even more important in coarse aggregates than in fine. Table LXXIII gives a suitable gradation for coarse aggregates.

TABLE LXXIII.—*Gradation of coarse aggregate*

	Percent by weight
Maximum size (mesh screen)	97–100
One-half size (mesh screen)	40–70
Number 4 sieve	0–6

(3) *Size.*—The maximum size of coarse aggregate depends upon the use to be made of the concrete. For plain concrete in mass construction the maximum size may be from 1½ to 6 inches. For thin reinforced members a maximum of ¾ inch is used, while rarely in reinforced work is a diameter greater than 1 inch advisable. The use of large stones in plain concrete is permissible, provided they are of good quality, well covered, and do not occupy more than one-third of the total mass.

■ 255. WATER.—*a. Function.*—The function of water in concrete is threefold:

(1) It unites chemically with the cement to form a binding material.

(2) It acts as a carrier for the cement, carrying it throughout the mass of the aggregate during the mixing.

(3) It acts as a lubricant between the particles of the aggregate.

b. Quality.—Water used for concrete should be clean and free from excessive amounts of oil, acid, alkali, organic, or other deleterious matter. Sea water is not as desirable as fresh water because of its corrosive effect on reinforcement and should not be used except in an emergency.

■ 256. PROPORTIONING CONCRETE MIXTURES.—*a. General principles.*—Concrete mixtures should be proportioned in accordance with the following principles:

(1) For any truly plastic concrete mixture, the strength of the concrete produced will vary as the ratio of moisture to cement content is varied, and the strength will be higher

as the water-cement ratio is lower. The relationship is a curve, and necessarily varies somewhat for any particular job. However, the curve relationship and the actual unit strengths obtained are quite constant. Control of the water content is therefore essential in order to obtain any particular desired strength.

(2) It is desirable also to control the amount of cement used. Increased cement increases workability. However, excessive cement in large sections causes excess internal heat, often resulting in cracking. Also, of course, for reasons of economy, it is desirable to use no more cement than necessary. Generally the amount of cement used is determined by adopting a certain volumetric ratio of cement to aggregates.

(3) From a consideration of the above the necessity of proper grading of aggregates can be seen, since it is only by obtaining properly graded aggregates that the cement and water content can be held down to figures giving the best results and still produce a workable mix.

(4) A practicable method of achieving the above results is to decide on a suitable water-cement ratio, obtain aggregates which, because of their grading, have only a relatively small percentage of void spaces, decide on a suitable ratio of cement to aggregates, and test the proposed mix for slump. (See *c* below.) If the slump is excessive, it may be possible to increase the aggregate percentages, particularly that of the large-sized aggregates, thus obtaining a better cement yield. Or if it appears most desirable to obtain a higher strength of concrete, the water-cement ratio can be reduced. If the slump indicates that difficulty will be had in placing due to lack of moisture and a truly plastic mix, the difficulty is probably due to an excess of fine aggregate. In this case the proportion of large aggregate should be increased. If the mixture appears harsh and lacking in workability, an effort should be made to increase this quality of the mix by better grading of aggregate and the introduction of additional fine aggregates, particularly fines. It may also be necessary to reduce the volume of the large aggregate. If this is not possible, consideration must be given to increasing the ce-

ment content (and water) or increasing the water-cement ratio (which of course will decrease the strength of the concrete). In addition, it may be possible to obtain vibrators for placing which will make the use of a harsher mix practicable. If the mixture appears to lack sufficient cement paste to fill the voids, a better grading of aggregates must be sought. If this is impossible, the ratio of cement volume to aggregate volumes must be increased. Finally when a mix is decided on, if the work is important and time is available, it is desirable to make test cylinders and test the strength of the proposed concrete at 7 and 28 days.

b. Strength of concrete.—(1) Table LXXIV gives the compressive strength of concrete as determined by the water-cement ratio.

TABLE LXXIV.—*Strength of concrete mixtures*

Water content in United States gallons per 94-pound sack of cement [1]	Assumed compressive strength at 28 days in pounds per square inch	
	([2])	([3])
8	1,750	2,750
7	2,300	3,300
6	3,000	4,000
5	3,800	4,900

[1] Surface water or moisture carried by the aggregate must be included as a part of the mixing water.

[2] Data published at time water-cement ratio strength law was announced in 1918. These values should be used in the absence of preliminary tests and careful control.

[3] Values representative of present-day cements.

(2) Table LXXV gives the approximate quantity of surface water carried by average aggregates which must be included as a part of the mixing water in computing water-cement ratios.

TABLE LXXV.—*Approximate quantity of surface water carried by average aggregates*

Aggregate	Gallons per cubic foot
Very wet sand	¾ to 1.
Moderately wet sand	About ½.
Moist sand	About ¼.
Moist gravel or crushed rock	About ¼.

c. Slump test.—The slump test is a convenient method of measuring the workability of a concrete mix. A conical shell of 16-gage galvanized metal with a base 8 inches in diameter, a top 4 inches in diameter, and an altitude of 12 inches is filled to overflowing with concrete rodded into the shell in 3 separate layers, each layer receiving 25 strokes of a ⅝-inch bullet-end rod 24 inches in length. The excess is carefully struck off and the mold is at once lifted, slowly and vertically. The amount of drop of the top of the mass below the original 12-inch height, measured in inches, is known as the slump and is a measure of the workability of the mix. Table LXXVI gives slumps which have been found suitable for mixes used in various types of structures.

TABLE LXXVI.—*Suitable slumps for concrete*

Type of structure	Slump (inches)	
	Minimum	Maximum
Massive sections, pavements, and floors laid on ground	1	4
Heavy slabs, beams, or walls	3	6
Thin walls and columns, ordinary slabs or beams	4	8

d. Trial batches.—Table LXXVII shows trial mixtures for various water-cement ratios. The exact proportions should be determined by making up full-sized trial batches, using the aggregates selected for the job.

TABLE LXXVII.—*Trial mixtures for various water-cement ratios*

Water-cement ratio 5½ gallons per sack

Slump (inches)	Trial mix dry compact volumes for maximum size of aggregate indicated	
	1 inch	2 inches and over
½ to 1	1:2:3	1:2:3½.
3 to 4	1:1¾:2½	1:1¾:3.
5 to 7	1:1½:2	1:1½:2½.

Water-cement ratio 6 gallons per sack

½ to 1	1:2¼:3¼	1:2¼:4.
3 to 4	1:2:3	1:2:3½.
5 to 7	1:1¾:2½	1:1¾:3.

Water-cement ratio 6¾ gallons per sack

½ to 1	1:2½:3½	1:2½:4.
3 to 4	1:2¼:3¼	1:2¼:3¾.
5 to 7	1:2:3	1:2:3½.

Water-cement ratio 7½ gallons per sack

½ to 1	1:3:4	1:3:4¾.
3 to 4	1:2½:3¾	1:2½:4¼.
5 to 7	1:2¼:3½	1:2¼:3¾.

NOTES

1. Water-cement ratios indicated include moisture contained in the aggregate.
2. Proportions are given by *volume, aggregate dry,* and *compact.* Thus 1:2:3½ indicates 1 volume of cement, 2 volumes of sand, and 3½ volumes of coarse aggregate.
3. If the aggregates are to be measured in the *damp* and *loose* condition they will occupy greater volumes than when dry and compact. Amount should be determined by test. Approximate average value for sand, 20 percent; for coarse aggregate, 6 percent.

■ 257. QUANTITIES OF MATERIALS.—The following table may be used to estimate quantities of materials required in concrete construction.

TABLE LXXVIII.—*Quantity of materials*

Mix by volume job damp materials	Materials per cubic yard of concrete			1 bag batch (cubic feet)
	Cement (sacks)	Sand (cubic feet)	Stone (cubic feet)	
1:1¼:2	9.6	12.0	19.1	2.82
1:1½:3	7.6	11.4	22.8	3.55
1:2:3	7.1	14.2	21.3	3.82
1:2:3.5	6.5	13.0	22.7	4.16
1:2:4	6.0	12.0	24.0	4.47
1:2.2:3	6.8	15.0	20.4	3.97
1:2.2:3.5	6.3	13.9	22.2	4.26
1:2.5:3	6.5	16.1	19.4	4.18
1:2.5:3.5	6.0	15.0	21.0	4.49
1:2.5:4	5.6	14.0	22.4	4.83
1:2.5:5	5.0	12.5	25.0	5.43
1:3:5	4.7	14.1	23.5	5.76
1:3:6	4.2	12.6	25.2	6.38
1:3¼:4	5.2	16.2	20.8	5.21
1:3¼:5	4.6	14.5	23.2	5.82
1:3¾:5	4.3	16.0	21.4	6.32
1:3¾:6	3.9	14.7	23.5	6.89
1:1½	15.5	23.3		1.77
1:2	12.8	25.6		2.13

■ 258. MIXING CONCRETE.—*a. Hand mixing.*—The mixing platform must be tight and of sufficient size to accommodate men and materials. A suitable size for single batches is about 10 feet square. Batches should not exceed 1 cubic yard or be larger than can be placed in 30 minutes. All materials should be stored near the mixing platform and should be measured by shoveling them into bottomless boxes set upon the platform. (See table LXXIX.)

TABLE LXXIX.—*Dimensions for measuring boxes*

Capacity (cubic feet)	Inside measure (inches)		
	Length	Breadth	Height
1	12	12	12
1¼	15	15	9⅝
1½	15	15	11½
1¾	15	15	13½
2	18	18	10⅝
2¼	18	18	12
2½	18	18	13⅜
2¾	18	18	14⅝
3	18	18	16

A satisfactory procedure for hand mixing is as follows: Spread the sand for a batch evenly on the platform to a depth of 3 or 4 inches. Spread the cement upon the sand. Mix sand and cement until the mixture is uniform in color. Three turnings will usually be sufficient. Add the quantity of water as determined by the water-cement ratio and mix. Spread mortar out and add coarse aggregate, first wetting the coarse aggregate if it is drier than was assumed in designing the mix. Turn the mass over three or four times until thoroughly mixed.

b. Machine mixing.—Machine mixing is superior to hand mixing, both in quality of concrete produced and in economy of time and labor, and should be the rule if a mixer is available. Known volumes in measured wheelbarrows or two-wheeled buggies should be used on large jobs to save time and effort.

c. Time.—Machine mixing should continue for at least 1 minute after all the materials are in the mixer. Little is gained by continuing the operation beyond 2 minutes.

■ 259. FORMS.—*a. General.*—Forms must be tight, rigid, and strong enough to sustain the weight of the concrete. In vertical members the hydrostatic pressure of green concrete may be 145 to 150 pounds per square foot per foot of height. Ease of erection and removal must be considered.

b. Materials.—White pine, spruce, and the softer southern pines are the best lumber for forms. All lumber should be dressed at least on one side and both edges. The edges may be cut square or tongued and grooved. If only poor lumber is available, sheet metal, plywood, or tar paper will give a smooth surface and prevent leakage of cement paste from the forms. Forms should be constructed with a view to using the material again either for forms or for other purposes. (See fig. 150.) Either 1- or 2-inch boards are suitable for lagging. One-inch lagging requires supports spaced 18 to

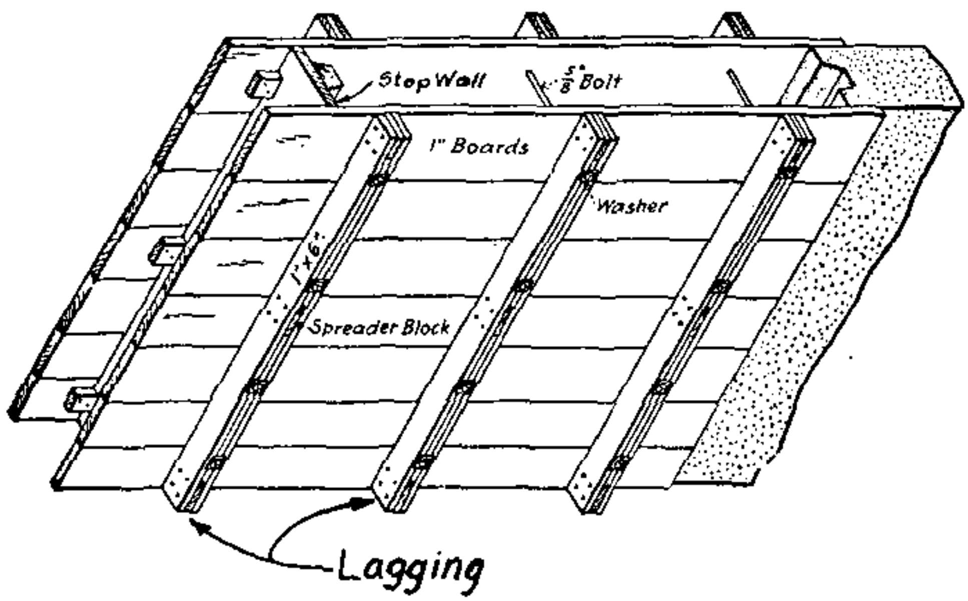


FIGURE 150.—Sectional wall form.

24 inches apart. Two-inch lagging requires supports 4 to 5 feet apart. Studding or joists should be 2 by 4 inches to 2 by 6 inches for 1-inch lagging and 4 by 6 inches to 4 by 10 inches for 2-inch lagging. Concrete can often be placed in an excavation without exterior forms.

c. Bracing.—Forms must be carefully braced to prevent deformation. One method is by the use of external inclined braces. (See fig. 151.) To prevent spreading, the forms should be fastened together with wire or bolts (see figs. 150 and 152) which become imbedded in the concrete and which are cut on the outside when the forms are removed. Spread-

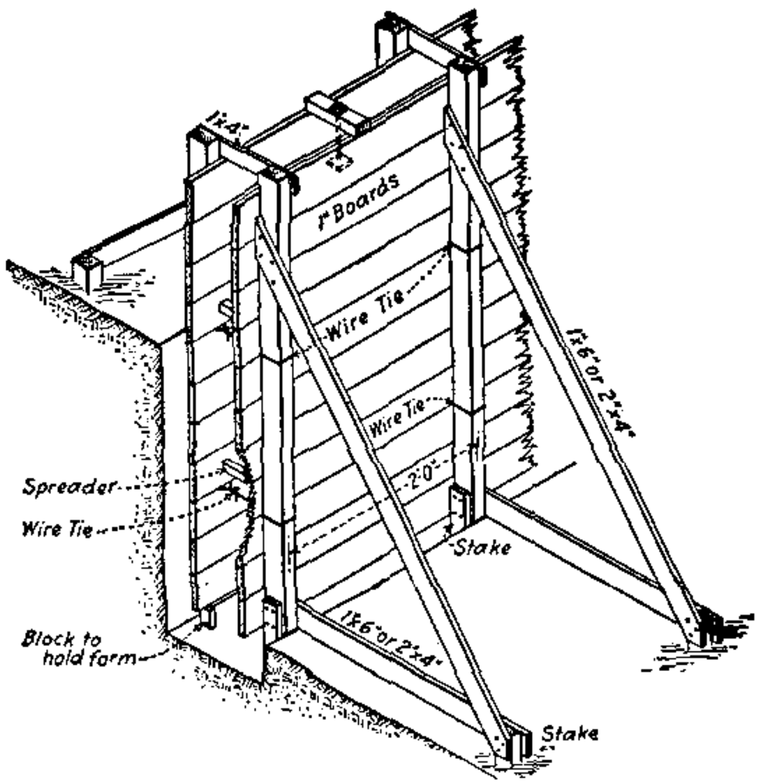


FIGURE 151.—Typical externally braced form.

ers, removed as the concrete rises, may be used to keep forms apart. Flat floor forms must be braced from below. For column forms (fig. 153) clamps are used to brace and enclose the forms.

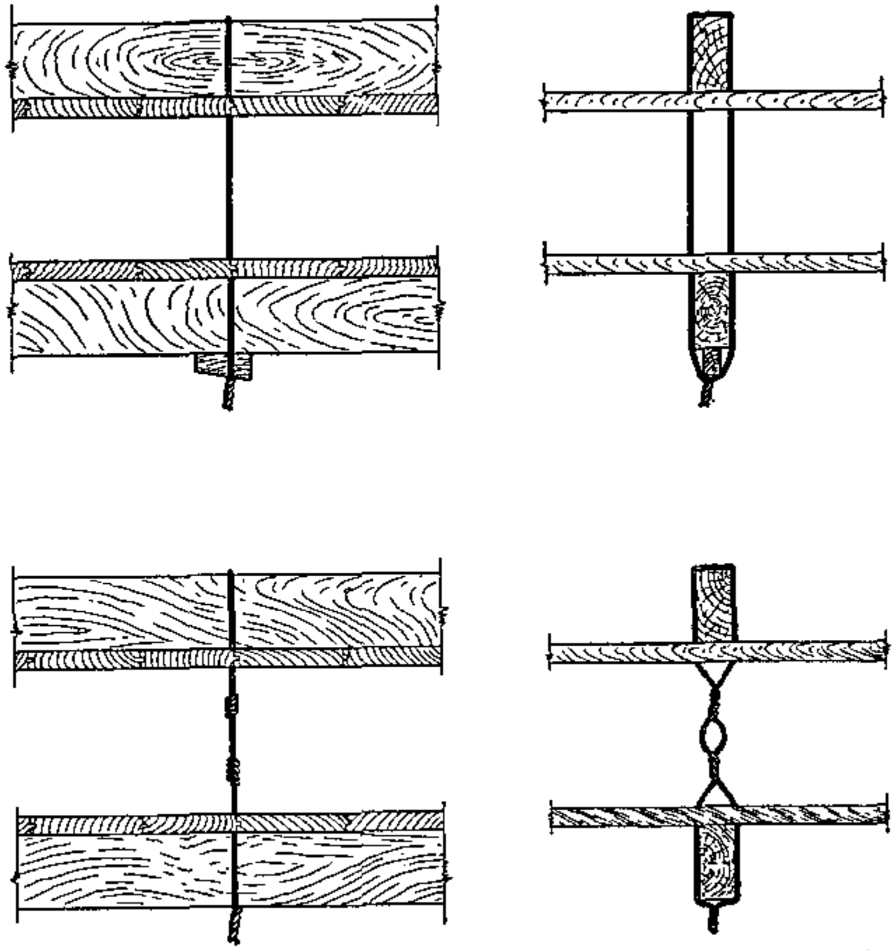


FIGURE 152.—Tying forms with wire.

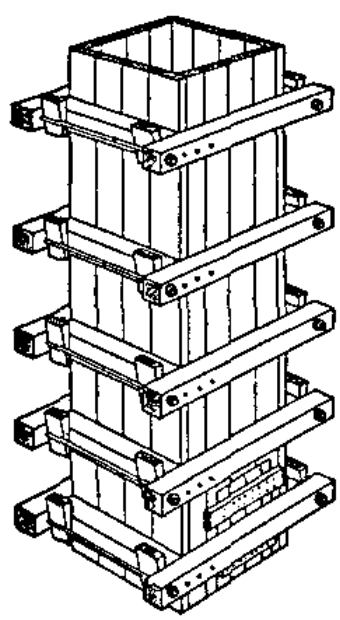


FIGURE 153.—Column form.

d. Cleaning.—Before concrete is deposited all debris, such as sawdust, shavings, etc., must be removed. If the form material has been used previously, all dry concrete must be removed from the inside of the forms. The forms should be wet or oiled before the concrete is placed.

e. Removal.—It is vitally important to allow sufficient time for the proper hardening of concrete. Usually, forms should remain in place longer for reinforced than for plain concrete and longer for horizontal than for vertical members. The following data will serve as a guide:

(1) *Walls in mass work.*—One to 3 days.

(2) *Thin walls.*—In summer, 2 days; in cold weather, 5 days.

(3) *Columns.*—In summer, 2 days; in cold weather, 4 days. Concrete has usually hardened sufficiently to permit the removal of forms when it has a distinctive ring under the blow of a hammer. The basic rule to be observed is "It is better to leave the forms on too long than to remove them too soon."

■ 260. PLACING CONCRETE.—*a. Prevention of segregation.*—In the placing of concrete, great care must be exercised to prevent segregation. Forms should be filled evenly from several points. Filling continuously at one point allows the material to segregate as it flows a considerable distance to fill the form.

b. Laitance.—Laitance is a whitish, chalky substance consisting of the finest particles of the cement, together with some of the clay and silt of the aggregate. It comes to the surface of freshly mixed concrete, and, as it hardens very slowly and never acquires much strength, constitutes a plane of weakness unless thoroughly removed. The existence of laitance indicates that an excess of water is present in the concrete mixture.

c. Tamping.—Dry concrete should be tamped in layers of 1 to 2 feet in thickness. Wet concrete requires little or no ramming but should be spaded to remove entrained air and to bring the concrete into all corners of the forms. Mechanical vibrators permit the use of a more sluggish or leaner mixture and make possible the flow of concrete through small openings and around closely spaced reinforcement. Some tamping is always necessary when concrete is placed in narrow sections or confined places.

d. Delays in pouring.—It is highly desirable to pour concrete continuously until the structure is completed, since a stoppage forms a plane of weakness. Where this is impossible, stop boards should be placed where shear is a minimum; that is, vertically in the center of the span and at right angles to the axis of the span in the case of beams and slabs. In pouring walls or footings a section should be marked off with stop boards equivalent to a day's pouring and that section built to its full height. (See fig. 150.)

e. Joints.—Construction joints are necessary to allow for the change in volume of the concrete under the influence of temperature changes. Expansion joints in floors exposed to the weather, sidewalks, curbs, etc., are usually not more than 5 or 6 feet apart, while in thicker construction they can be farther apart. Retaining walls and abutments have vertical contraction joints 25 to 50 feet apart, and culverts and sewers, which are less exposed to temperature changes, have joints 60 to 75 feet apart.

f. Bonding.—In joining fresh concrete to concrete which has hardened, all laitance, loose material, and dirt should be removed from the top of the old concrete, and the surface roughened with a pick. A coat of cement grout about ½ inch thick should be applied and carefully covered with a thin layer of concrete. Pouring of fresh concrete may then be resumed. Other precautions for securing a good bond include embedding timbers in the old concrete before it has set to provide grooves in the surface when removed, partially embedding large stones in the upper surface of the old concrete which serve to dowel the old and new surfaces together, or using steel dowels.

■ 261. CURING.—*a. Moisture.*—Concrete hardens because of the chemical reactions between cement and water. It is imperative that the concrete be prevented from drying out too rapidly. Tests have shown that a concrete which is allowed to dry out immediately will usually reach a strength of not more than 50 percent of the strength of similar concrete kept moist over the entire period of curing.

b. Temperature.—Figure 154 shows graphically the effect of different conditions of temperature on the strength of concrete during the 28-day period.

c. *Methods of curing.*—The main problem of curing in normal temperatures is to prevent too rapid evaporation of the

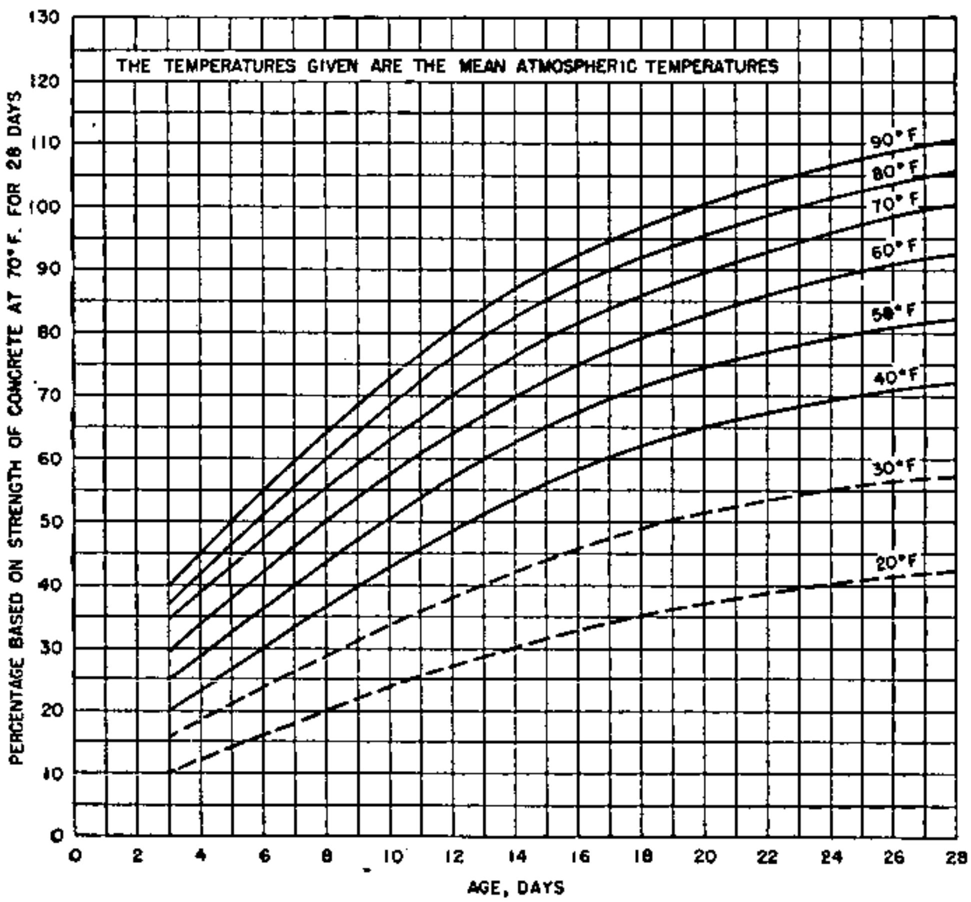


FIGURE 154.—Effect of temperature on strength of concrete.

water in the concrete. Wet burlap, canvas, straw, or earth coverings can be placed over the surface and, if kept continuously wet, will give good results. Wetting the forms before placing the concrete will prevent the wood from absorbing the water in the concrete. A flat surface can be kept wet by building small earth dykes around the surface and then flooding it. The surface may be kept continuously wet by water from small holes punched in a water pipe. Exposed surfaces should be prevented from drying out for at least 5 days, and

10 days' curing is much better. For curing in cold weather, see paragraph 262*c*.

■ 262. SPECIAL PROCESSES.—*a. Watertight concrete.*—Concrete under moderate hydraulic pressure can be made waterproof. The amount of mixing water should be a minimum and, in any case, should not exceed 6 gallons per sack of cement. Sound aggregates of low porosity must be used, particular attention being paid to grading, thorough mixing, and proper curing. The structure should be poured continuously. The concrete, while still wet, may be coated with a rich cement mortar or, if the impermeable surface is to be below ground level, an impermeable bituminous material may be applied. Several alternate layers of asphalt and roofing felt placed between layers of concrete give good results.

b. High early strength cements.—(1) *General.*—The use of high early strength cements is particularly important in military construction. It reduces the time of curing from a minimum of 5 days to 2 days, and permits the use of a structure in a much shorter time. High strength at an early age can be secured either by the addition of accelerating agents to standard portland cements or by the use of special cements designed to give high early strength.

(2) *Accelerating agents.*—The most commonly used accelerating mixture is calcium chloride. An 8-percent solution in water is used in mixing the concrete. This solution may be conveniently made by adding 5 pounds of calcium chloride to each 10 gallons of water, and will reduce the time of set by 25 to 30 percent. By applying live steam, up to 80 pounds per square inch gage pressure, the hardening of concrete can be greatly accelerated. Concrete exposed to steam under pressure for 24 hours has reached a compression strength in 2 days twice as great as unsteamed concrete reaches in 28 days.

c. Handling concrete in cold weather.—(1) *Effect of freezing temperatures.*—Low temperatures greatly slow up the set of concrete. When the temperature falls below freezing, the expansion of water in freezing exerts a force sufficient to destroy the cohesion between the particles of the green concrete, and the concrete is rendered worthless.

(2) *Methods of protection.*—In freezing weather, the temperature of concrete should be not less than 70° F. for the first 3 days. The following methods may be used to maintain the proper temperature in the concrete during curing:

(*a*) Heat the water and aggregates before mixing. (Concrete should not have a temperature above 100° F.)

(*b*) Cover concrete in place with insulating material, such as straw, manure, etc.

(*c*) Provide artificial heat by canvas enclosures heated with salamanders, live steam, or unit heaters.

d. Placing concrete under water.—If practicable, concrete should not be placed under water, but instead the area of operation should be unwatered. However, many times this may not be possible. Concrete can be successfully placed in water where there is little current. Contact of the concrete with water does not affect the interior of the mass but does wash out some of the cement at or near the surface. Concrete is commonly placed under water by one of the following methods:

(1) *Drop-bottom buckets.*—The bucket should be raised and lowered slowly to avoid backwash.

(2) *Tremie.*—A tremie is a large tube, 12 inches or greater in diameter, which is kept filled with concrete, the concrete escaping through the bottom as the tube is shifted along the working surface.

(3) *In cloth or paper bags.*—The bags are loosely filled, and, when placed in position, flatten out, and their contents cement themselves together.

■ 263. REINFORCED CONCRETE.—*a. General.*—Ordinary concrete is about 10 times as strong in compression as in tension. For this reason, if full advantage is to be taken of the compressive strength of the concrete of any member subject to transverse stresses, it will be necessary to add material to withstand the tensile stresses developed. For this purpose steel rods or mesh are used to reinforce the concrete.

b. Reinforcing steel.—(1) *Types.*—Round or square reinforcing steel bars may be either plain or deformed. Mesh may be composed either of expanded metal or of woven wire netting. Mild steel is generally considered the best material for reinforcing rods.

(2) *Sizes.*—Rods are usually cut and bent to shape at the site of the work. The sizes of steel should be kept to an absolute minimum. Good practice calls for the proportioning of steel so that the sizes vary in diameter between ⅛ inch and 1¼ inches. The area of steel should be from 1 to 3 percent of the effective area of the concrete.

(3) *Bond.*—Bond is affected by the shape and condition of surface of the reinforcing rods. The size of the rod does not affect the unit bond strength. Square bars are only about 75 percent as strong in bond as round ones of the same cross section, and flat bars have even less strength. Oil and paint reduce bonding strength. Rust scales should be removed from reinforcing material by the use of a stiff wire brush.

(4) Reinforcement should be placed at least 2 inches from the nearest face of the concrete section.

c. Reinforcing concrete shelters.—Concrete, properly reinforced, is highly resistant to artillery fire. Reinforcement such as railroad rails and I-beams placed in layers and covered with a thick layer of concrete does not resist the shock of artillery fire, as the concrete is either destroyed or moved bodily from such reinforcement. Reinforcing should consist of small rods or mesh, large steel sections being used only when small sections are not available. The most suitable type of reinforcement is a grid of ½-, ¾-, or 1-inch soft steel bars arranged to form squares of 6 to 10 inches and wired together at the crossings. The weight of the reinforcement should be 0.75 to 1 percent of the total weight of the concrete. Joints in bars must have a lap of not less than 50 diameters. The grids should be placed at least 3 inches from the inner and outer surfaces of the shelter. Good practice in placing the reinforcing is as follows:

(1) Use steel bars or rods not over 1¼ inches in diameter or heavy mesh having an effective area of at least ¼ square inch per foot of width.

(2) Place reinforcing parallel and close to the inner surfaces of the roof, walls, and floor.

(3) Place additional reinforcing material close to the outer surface to assist in resisting the penetration of the

shell and to distribute the stresses to the mass of the concrete.

(4) Tie the two layers of reinforcing together with stirrups to resist shear and splitting of the concrete.

SECTION II

QUARRY OPERATIONS

■ 264. SELECTION OF SITE.—*a. General.*—Because of the tonnage of materials involved and the probable inadequacy of transportation facilities in the theater of operations, it often will be necessary for military engineers in the forward areas of the combat zone to open and operate small temporary quarries for local supply in the construction and maintenance of routes of communication. Quarries established in rear areas will usually be of large capacity and of a permanent nature.

b. Reconnaissance.—The search for possible quarry sites, with a view to limiting the amount of transportation necessary on road work, is a function in each area of the unit engineer. Valuable information as to available sites often can be obtained from maps and reports and from local inhabitants, especially highway engineers and contractors, familiar with the area.

c. Bases for selection.—The following points should be considered in the selection of a quarry site:

(1) *Quality of rock.*—The best rocks for road construction are those which are hard, tough, and have good cementing value.

(*a*) Trap rocks possess the required qualities to the highest degree and are most suitable for heavy duty roads.

(*b*) Granite is hard, igneous rock, much used in road construction. It is lacking in cementing value, so that some suitable material must be supplied to correct this deficiency.

(*c*) Limestone is soft and brittle but possesses excellent cementing value. It may be used for the artificial foundation of a macadam road if a tough wearing course is provided. If it is used for the entire crust, heavy maintenance will be required.

(*d*) Sandstone is soft and brittle and lacks cementing value. It may be used as an artificial foundation.

(*e*) Military necessity often will require the use of field stones, but they are variable in composition and in the effects of weathering wear unevenly and require heavy maintenance.

(2) *Quantity.*—The quantity of rock available at any site depends upon the thickness and uniformity of the beds and upon the dip of the strata. Horizontal or slightly inclined strata are favorable signs of a large supply, while a stratum dipping sharply away from the face may indicate a limited available supply because of the excessive work of removing the overburden of earth or unusable rock as the quarrying proceeds.

(3) *Location.*—The most favorable location for a quarry is on a hillside. Such a location facilitates drainage and the removal and disposal of overburden and permits the maximum utilization of gravity in moving materials through the various quarry operations.

■ 265. DEVELOPMENT AND OPERATION.—*a. Removal of overburden.*—Once the site has been selected, the first step is to lay bare the surface of the rock, removing all the overburden. As a general rule the rock should be kept clean for at least 20 feet behind the working face. Small quantities of overburden can be removed with pick, crowbar, and shovel. For larger operations blasting and power machinery may be necessary.

b. Access.—A well-constructed road, connecting the quarry with the route over which the crushed stone is to be transported, is essential. A part of the overburden often may be used in constructing a suitable foundation for the road.

c. Working faces.—In developing a quarry, large working faces and a floor designed to utilize gravity are desirable. On long hillsides several faces may be developed by offsetting each from the adjoining face. On high hillsides faces may be developed one above the other by terraces. A working face should be attacked throughout its entire height, and the product dropped to its foot. A rough rule for the length of face in a military quarry is that each linear yard should produce one cubic yard of material per day.

d. Extraction.—In small quarries, hand drills and explosives are used in loosening the rock from the working face.

Power drills greatly speed up drilling operations. In excavating 1 cubic yard of solid rock, ¼ to ¾ of a pound of 40-percent dynamite is required. For estimating purposes, assume ½ pound per cubic yard of rock. The TNT carried in platoon demolition sets can be used for quarrying in an emergency but it is not as satisfactory as 40-percent dynamite for this work.

e. Breaking up.—The large pieces of rock blasted from the face may be broken into sizes suitable to the crushers by explosives or by hand, depending upon the kind of rock and the plant and labor available. For estimating purposes, assume a man can break, by hand, 1 cubic yard of rock per day.

f. Transportation.—Transportation to the crushers may be by wheelbarrow, cart, wagon, truck, or narrow gage railroad. In small operations it may often be convenient to feed the rock into the crushers by inclined chutes leading from the working platform.

g. Crushing.—On small emergency jobs, rock may be crushed by hand, but generally crushing is done by portable mechanical crushers ranging in capacity from 10 to 40 tons per hour. Larger crushers with capacities up to 600 tons per hour are used in permanent installations. One cubic yard of solid rock in the quarry face will produce approximately 1.9 cubic yards of crushed rock. (See par. 39*b*.)

h. Screening and storage.—In small operations crusher-run rock may be used without screening. In larger plants bucket elevators carry the output of the crusher to elevated flat reciprocating or revolving circular screens so mounted that the broken stone will gravitate from one to the other. Bins are arranged so that the products from each screen will fall into a separate compartment from which they may be loaded by gravity into vehicles or cars as desired. Storage bins are very useful in that they permit continuous operation of the crushers regardless of nonuniform hauling operations. If no bins are provided, the crusher must either shut down when no transportation is available or else the crushed rock must be piled on the ground and reloaded into vehicles by hand or elevating machines.

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